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# A tale of gold and blood: The unintended consequences of market regulation on local violence[*]

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## Abstract

How can a small change in fiscal accountability boost violent disputes for valuable natural resources? In this paper, we investigate a regulatory change in Brazil that greatly reduced governmental monitoring capacity against gold laundering and we show how this affected violence in illegal gold-mining sites. Because the new regulation introduced in 2013 made it harder for authorities to find illegal gold transactions between miners and first-buyers, demand for it increased and boosted competition for illegal mining sites, leading to more violence. To verify this, we devise a theoretical model and test its implications using a unique database combining gold deposits, Indigenous Territories, Natural Conservation Areas, environmental crimes, deforestation, and homicide rates. With a difference-in-differences design, we find that municipalities more exposed to illegal mining experienced extra 8 homicides per 100,000 people - or an increase of roughly 20% - after the regulation was passed. We also find that, as the model predicts, this large effect is likely coming from increasing illegal activity, which we measure with data on both deforestation and environmental crime reports.

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# 1. INTRODUCTION

The economic literature has long studied how the presence of natural resources can lead to violent conflict - a phenomenon commonly known as *resource curse* (Angrist and Kugler, 2008; Berman et al., 2017). This typically happens in developing nations, where fighting over those valuable resources is possible due to low government capacity to enforce property rights; and it has been shown to be an especially relevant issue when there exists an illegal market for those products (Idrobo et al., 2014). In such case, government enforcement is even harder, because authorities need to invest more in monitoring capacity to find and punish illegal production and transactions. In turn, players operating under the government's radar are left with even fewer alternatives for dispute resolution besides using violence to defend their position (Chimeli and Soares, 2017). In this context, where direct government monitoring is challenging, regulation defining property rights might not suffice to deter conflicts if incentives are not carefully designed for private players to enforce the rules themselves.

One common example of such kind of properly designed regulatory incentives happens when governments take advantage of the relationship between market players along production chains to enforce tax payments. This is the case of Value Added Tax (VAT) credit schemes, which work to cope with informality - i.e., to deal with players who do not comply either with tax or other bureaucratic requirements. In short, these tax credits encourage formal players in each stage of production only to negotiate with other formal players, which in turn works to increase formalization in the entire production chain (Paula and Sheinkman, 2010; Pomeranz, 2015; Rauch, 1991).

Surprisingly, however, even though illegal markets are organized in production chains *and* many governments or other organizations create incentives along different stages of production to enforce regulation[1], the link between incentives for players to enforce against illegal activities and violent conflict still remains unexplored. Intuitively, governments with limited enforcement capabilities may encourage monitoring via private players and therefore affect the equilibrium levels of illegal activities and violence. This is what we study in this paper, both theoretically and empirically, thus bridging the gap between the literature on taxation and informality and that on illegal markets and violence.

To do this, we explore a natural experiment in the case of illegal gold-mining in the

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[1] See examples of environmental and food safety certification policies in Foster and Gutierrez (2013) and Tran et al. (2013). Other examples of certification policies include OCDE's guidelines for conflict minerals(OECD, 2016); or in FSC's non-governmental forest protection program, described at https://us.fsc.org/en-us/what-we-do.

Brazilian Amazon. In Brazil, government-regulated local stores - the *first-buyers* - are the main buyers of raw gold produced by small miners and they are obviously only supposed to purchase it legally. Before 2013, they were charged with the legal responsibility of screening sellers for mining permits and keeping documentation to prove their gold was in good standing. In 2013, however, a regulatory change exempted first-buyers from such responsibility and in practice greatly increased their incentives to purchase illegal rather than legal gold. Hence, drawing from what we observe in the context of VAT and informality, we would expect the new regulation, by changing the level of private monitoring downstream the production chain, to alter the equilibrium level of illegal activity upstream, in the supply side. In turn, because of how disputes are usually solved in illegal markets, this also changes the equilibrium level of violence.

We formalize the mechanism behind these events in a general equilibrium model - which we draw partially from Paula and Sheinkman (2010) - with first-buyers and gold miners both choosing whether to operate legally or illegally depending on the level of private monitoring induced by the government. We add to this model the elements from Castillo et al. (2020), which provide the equilibrium level of violence in the illegal market. By combining these two frameworks, we are then able to study the theoretical connection between incentives to monitor downstream (first-buyers) and the level of illegal activity and violence (miners). Indeed, we demonstrate theoretically that the regulatory change affects the cost function of first-buyers, since their risk of being punished for buying illegal gold decreases. Moreover, because first-buyers can always re-sell gold legally[2], illegal gold becomes more profitable and demand increases. This encourages more miners to supply gold illegally and increases competition. In this environment with weak property rights and low access to formal conflict resolution, disputes are often solved with the use of force, and thus violence increases.

To test our proposed hypothesis and mechanisms, we take advantage of the regulatory shock to enforcement incentives that happened in Brazil in 2013. Still, we must overcome the fact that data on illegal gold-mining is scarce, mostly non-existent, and without it we cannot infer which places were affected by the new regulation. Again, Brazil offers the ideal setting for this, because large portions of its territory - especially in the Amazon - are marked as *protected areas*, such as Indigenous Territories and Natural Conservation Areas, in which no mining of any kind is allowed. At the same time, there is ample evidence that miners enter these areas to mine gold that will later be sold illegally to first-buyers

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[2] Indeed, as described in details by Brazilian authorities (Ministério Público Federal, 2020), first-buyers work effectively like an official *gold-laundering* institution, buying illegal gold and then re-selling it legally. This happens because, once gold is acquired by first-buyer, one may assume that it fulfills the legal requirements.

(Ministério Público Federal, 2020). Hence, we tackle the challenge of finding areas more or less exposed to illegal gold-mining activity by combining unique geocoded data on the location of mineral deposits, Indigenous Territories and Conservation Areas. In particular, we expect municipalities that have gold deposits inside protected areas to be more exposed to illegal gold mining activity. Consequently, these places should observe more violent disputes after the law is passed.

With these data ingredients, we organize our empirical strategy as a difference-in-differences design, contrasting the differential effect of the regulatory change across municipalities that are differentially exposed to illegal gold-mining. Identification thus stems from both the the timing of the shock and the plausibly exogenous location of gold deposits with respect to protected areas within each municipality.

With this design we find that municipalities more exposed to illegal gold-mining experienced roughly eight additional homicides per 100,000 people - or close to a 20% increase - after the regulatory change in 2013, compared with less exposed locations. These estimates are robust to the inclusion of controls for different urbanization trends, economic growth, and GDP composition that could be both a result of the gold-mining activity and a confounding cause of violence. Moreover, because our sample covers many different federal states, we include state-specific trends to account for regional institutional and economic changes over time non-parametrically.

Some concerns arise about whether we are really observing something specific to the gold market, and thus driven by our proposed mechanism, or some general trend in the illegal mining market. We provide evidence that the latter is not the case, and only violence linked to illegal *gold* mining is increasing. Alternatively, it could also be that using protected areas to identify illegal mining activity could be misleading, since these areas are already prone to conflicts between conservationists and farmers or loggers. We show, however, that violence does not seem to come from the existence of protected areas per se, but specifically from the interaction of these areas with the existence of gold deposits.

Finally, we must verify the mechanisms implied by our conceptual framework. In other words, we should observe not only violence increasing in places exposed to illegal gold-mining, but also the *level* of illegal activity itself increasing more in those more exposed locations. We test this by looking for common signs of increasing mining activity in the forest. Specifically, we use geocoded data on deforestation and on mining-related environmental crimes that are happening inside protected areas, and we find that both are increasing more in places exposed to gold-mining, suggesting that illegal gold-mining activity indeed intensified after the regulatory change. Deforestation, for instance, increased

about 10 square kilometers[3] on average in protected areas exposed to illegal gold mining after the regulatory shock. Moreover, the probability of finding and issuing fines to illegal miners inside protected areas exposed to gold deposits increased at least 5 percentage points more versus non-exposed areas. These results support our theoretical prediction that the reduction in governmental monitoring capacity against "gold laundering" boosted demand for raw illegal gold and its production, leading more miners to compete violently for control of illegal mining sites, with its side effect on deforestation.

Our findings contribute to the literature on the adverse effects of the presence of natural resources on development and, notably, on violence (Angrist and Kugler, 2008; Dal Bó and Dal Bó, 2011; Dube and Vargas, 2013). We show that valuable minerals - such as gold - are associated to violence in the Brazilian Amazon, much like in other mining regions (Berman et al., 2017; Stoop et al., 2019). We add to this by showing how the delicate equilibrium in *Resource Cursed* regions can be tipped by even the smallest change in enforcement policies. We believe this is an important implication not only in this context, but also for the design of all kinds of policies aimed at discouraging production processes with high social and environmental costs. For example, certification of origin schemes, which are supposed to ensure that production processes use best management practices; i.e., they assure consumers that they are not buying goods supplied by farmers who invade Conservation Areas; or loggers who cut down endangered trees; or miners extracting conflict minerals. In these contexts, our results suggest that making private monitoring agents truly liable for the verification procedure is crucial for effective enforcement.

Our findings also contribute to the growing literature about violence and conflicts in markets with poorly enforced property rights (Chimeli and Soares, 2017; Fetzer and Marden, 2017; Bandiera, 2003; Dell, 2015; Castillo et al., 2020). In a similar empirical setting, Idrobo et al. (2014) shows how illegal gold mining was one of the contributors to increasing violence in Colombia during the gold prices' boom after the financial crisis of 2008. In this case, they emphasize the importance of securing property rights to avoid violence. Our paper goes further in showing that the mere existence of regulation to guarantee property rights is not enough if enforcement strategies are poorly designed. To the best of our knowledge, we are the first to draw from previous work about the effect of VAT on informality (Paula and Sheinkman, 2010; Pomeranz, 2015) and show how similar monitoring incentives in downstream stages of markets with weak property rights not only affect the level of illegal activity upstream, but also may boost or deter violence. Moreover, we provide suggestive evidence that these private monitoring strategies could be an important tool to contain environmental degradation.

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[3] Which amounts to about 1,400 soccer fields.

Finally, we remark that our results here show that exempting front-line clients from monitoring the origin of their purchases can increase violent disputes upstream even in a context where previous land titling policies had presumably solved property rights issues - as is the case of Indigenous Territories and Conservation Areas in Brazil (Fetzer and Marden, 2017). This suggests that policies designed to solve property rights disputes cannot be assumed to work in a vacuum, relying only on government monitoring of violators, partly because it is really expensive to actively find and punish people invading protected areas in huge territories like the Amazon. In fact, laws delimiting protected areas likely need to be complemented by creating incentives for players in multiple production chains not to seek resources inside those lands.

The rest of the paper is organized as follows. The next section provides additional background about mining activity in the Brazilian Amazon. Section 3 introduces the conceptual framework and our guiding hypotheses. Sections 4 and 5 outline the data and the empirical strategy. Section 6 presents the main results and its mechanisms, as well as robustness checks. Section 8 concludes.

## 2. GOLD MINING AND VIOLENCE IN THE BRAZILIAN AMAZON

**2.1. Mining and selling gold prior to 2013** Gold has had an important role in Brazil since the country's first large deposits were found in the seventeenth century. Such discovery, followed by a large migration wave to the mining sites, allowed Brazil to become the largest producer of gold in the world between the $16^{th}$ and $18^{th}$ (Porto et al., 2002). More recently, although the country has lost positions in the ranking since then, it was still the world's $10^{th}$ largest producer in 2017, with a 2.6% market share.

Since the first gold deposits, mining sites have expanded from central Brazil to states of the Brazilian Amazon[4], which in 2017 accounted for one third of the gold output. The influx of people caused by this new gold rush did not bring only the benefits of urbanization and increasing income, but also was associated to massive deforestation, mercury contamination of rivers, and increasing violence.

One emblematic case illustrating this process is that of *Serra Pelada*, a massive gold deposit discovered in the state of Pará in 1979. After word spread out, in the course of less than five years, *Serra Pelada* attracted more than 100,000 people looking for fortune and it was said to be the largest open-air gold mine in the world at its peak. This gold rush devastated the forest and polluted the rivers where gold was mined. In fact, such contamination was so critical that hair samples from people living downstream mining sites

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[4] Acre, Amapá, Amazonas, Maranhão, Mato Grosso, Pará, Roraima, Rondônia, Tocantins.

showed mercury levels 15 times higher than the World Health Organization's tolerable standards (BMJ, 1992)[5].

As deposits depleted and controversies accumulated in *Serra Pelada*, the government made several unsuccessful attempts to close the mining site, followed by negotiations to extend its operation permit. These conflicts culminated in a large miners' protest against the closure of *Serra Pelada* in 1987, which ended in confrontation between workers and the police and left more than seventy people dead or missing. With the fresh memory of these events in mind, legislators elaborating the new democratic constitution in 1988 devised norms to formalize and regulate the activity of small-scale miners. Commonly referred to as *garimpeiros*, these miners typically worked alone, used rudimentary tools and had poor economic conditions.

But *garimpeiros* changed a lot since the 1980's and today are much better equipped and organized, using more expensive machinery and forming large cooperatives[6]. Still, they are relatively small players compared with big mining companies such as Anglo Gold Ashanti or Kinross Gold - at least based on official estimates[7].

Hence, the Brazilian mining sector can be roughly split in two types of players: large international mining companies and small-to-medium-scale mining entrepreneurs called *garimpeiros*. Among the regulatory requirements that apply to each of these two categories, one relevant aspect about *garimpeiros* is the type of mining permit they are required to possess in order to mine and sell whatever they explore. As opposed to the large companies, *garimpeiros* apply for a less demanding permit called *Permissão de Lavra Garimpeira* (PLG), which requires a much simpler environmental license and, more importantly, waives *garimpeiros* from performing what is called a Mineral Prospection Report (*Pesquisa Mineral*, in Portuguese) prior to application[8].

This procedure consists in looking for mineral deposits in a specific area and estimating how much they would produce. And this "Propection Report" is important, accor-

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[5] In 1992, the British Medical Journal released an article alerting that Serra Pelada's episode of mercury poisoning would likely surpass that of the Minamata Disaster, the worst case of such contamination ever reported. For perspective, the Minamata Disaster resulted in at least 600 people suffering from poisoning and 79 people dying from eating fish contaminated by mercury disposals from a factory in Minamata, Japan, in the first half of the $20^{th}$. This episode was so traumatic that "Minamata Disease" is still commonly used to identify the condition caused by mercury poisoning.

[6] Federal prosecutors and police estimate that the initial capital expenditures start at R$60,000 (roughly US$12,000 in 2020) and could be as high as two million Brazilian Reais (or roughly US$400,000).

[7] According to *Agência Nacional de Mineração* (ANM), *garimpeiros* produced an average of 15% of total gold output between 2005 and 2017.

[8] The reason for this more permissive regulation traces back to the notion of what was a *garimpeiro* in the 1980's, i.e. a small and poorly equipped individual who barely makes a living out of mining. Because of this vulnerable position, the activity performed by *garimpeiros* was seen as more of a short-term enterprise that could not wait for long government approval processes.

ding to Ministério Público Federal (2020), because it gives authorities an output estimate to compare with actual numbers reported at the moment of sale. Indeed, miners - big or small - have to prove they have a valid mining permit at the moment of sale, which works to inform authorities about the origin of minerals they produced. This procedure, combined with the potential size of deposits estimated during the prospective phase, should allow authorities to compare quantities and confirm that a mining site is not producing much more than what was estimated. Presumably, this would help guarantee that miners are not extracting minerals from places where mining is strictly forbidden by the Brazilian law, such as Indigenous Territories and Natural Conservation Areas. Moreover, this would also prevent tax evasion, which is likely to be the primary motivation for this permit system.

For big mining companies, this mechanism works coherently, because authorities have both the amount sold and the estimated output. In the case of *garimpeiros*, however, since they do not have to estimate the potential output of mineral deposits by the time they apply for *PLG* permits, authorities can never ascertain whether a mining site under *PLG* is producing an unreasonable amount of minerals. This is a crucial feature to explain why *garimpeiros* are much more likely to work illegally in areas where mining is not allowed. A common practice, for example, is to mine illegally in protected areas and then make it look like their product originates from mining sites with valid *PLG* permits when they sell it to front-line buyers of raw gold, or the "first-buyers" (Ministério Público Federal, 2020).

In our context, these first-buyers of gold produced by *garimpeiros* are typically small stores called *Ponto de Compra de Ouro (PCO)*, which are sometimes located close to big mining sites and are always linked to large financial institutions. They work under government authorization and they essentially buy gold from *garimpeiros*, levy taxes for this transaction and then transfer the metal to melting facilities. Turned into bars and stored in banks, this gold becomes a financial asset.

Since they are the typical buyers of raw gold in the Amazon, these *PCOs* act as an important front-line monitoring institution against illegally mined gold, because they are the ones who check and store documents provided by *garimpeiros* to prove the legal status of their gold, i.e. that it was mined from lands with valid government permits such as the *PLG*. Notably, all documentation on the origin of raw gold is kept by *PCOs* physically in-store, with no electronic accountability system.

Finally, at least prior to the 2013 regulatory change we explore in this paper, *PCOs* could be legally penalized for transacting illegal gold under the 1998 Anti-Money-Laundering

Law (Lei 9.613/1998)[9]. This gave *PCOs* incentives to do a good job in screening sellers' permits and documents, looking for irregularities and incompatibilities, at the risk of being punished in case authorities found out any wrongdoing.

**2.2. Gold-market regulatory changes in 2013** In 2013, a group of congressmen performed a political maneuver to amend some norms about gold transactions. They included these modifications in another law, which had nothing to do with mining[10]. These "smuggled" amendments specifically affected the acquisition of gold by *PCOs* from *garimpeiros*. Seemingly innocuous changes, they were approved as part of Law 12.844/2013 and substantially weakened the government's capacity to trace illegal gold-mining because of two main changes (Ministério Público Federal, 2020).

First, starting in 2013, *PCOs* were allowed to buy gold from *garimpeiros* under the principle of *Good Faith*. This meant they could simply **assume**, without liability, that all documents provided by sellers were legitimate. Hence, the only ones at risk of being punished for transacting illegal gold were the *garimpeiros* themselves. *PCOs* in turn, at the moment of purchase, were only required to collect *garimpeiros*' IDs and a PLG numbers proving the origin of the gold and then keep copies in store for 10 years. In practice, *PCOs* were much less inclined to search thoroughly for irregularities and report them, leaving this to central authorities. The issue with this redistribution of monitoring responsibility is that all documentation can only be found physically in-store at *PCOs*, and thus auditing authorities have to go down to each of them in person to manually look for suspicious transactions.

The second main change is that Law 12.844/2013 also allowed for a plethora of agents that did not work directly as *garimpeiros* to sell gold to *PCOs*. Like *garimpeiros* themselves, these other people would only need to present documents linking the product to a valid mining permit. This increased monitoring costs for authorities as well, since now they would need to screen a much larger pool of individuals selling gold. This opened the door for a variety of criminal actors, such as drug dealers, who could now buy illegal gold and then resell it to *PCOs* to launder their money, with a lower probability of being tracked by authorities[11].

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[9] This law was designed in such way that all parties participating in operations with illicit money and goods could be prosecuted and punished if they failed to report potential violations.

[10] The amendment was included during a legislative session meant to convert a Medida Provisória - a temporary executive act - into a permanent law. The original Medida Provisória was about agricultural subsidies, but strong lobby from the National Association of Gold Producers and Buyers (ANORO) caused the inclusion of a handful of important articles regulating gold transactions between *garimpeiros* and first buyers, the *PCOs* (Ministério Público Federal, 2020).

[11] More details in a recent news article: https://apublica.org/2020/06/enquanto-forca-tarefa-investiga-

In sum, the new set of rules pulverized the number of transactions and agents the government had to monitor to enforce the prohibition against raw gold originating from protected areas. In practice, authorities were left with expensive alternatives such as police raids against *garimpeiros* in the forest or extensive searches through *PCOs'* files. This reduced PCOs' incentives to avoid dealing with illegal suppliers and turned them in a sort of "gold laudering" institution (Ministério Público Federal, 2020), increasing the cost of monitoring transactions and ultimately boosting demand for illegally mined gold. In turn, illegal gold-mining became more attractive, leading to more miners in mining sites and consequently more violent disputes. In the next section, we formalize this argument with a conceptual framework and outline the main testable propositions for the empirical part.

## 3. CONCEPTUAL FRAMEWORK

The conceptual framework developed in this section broadly shows how exempting *downstream* first-buyers from responsibility for buying illegal products alters their cost function, shifting their demand towards illegal suppliers *upstream*. In other words, producers are more likely to run activities illegally when *downstream* first-buyers are not held accountable for the product they buy. Furthermore, because illegal activities lack well-defined property rights and access to dispute-resolution in courts, they are usually associated to violent competition. Therefore, by inducing illegal production, reduced monitoring responsibility *downstream* stimulates violence *upstream*.

This conceptual framework can be applied to explain violence outcomes in many different illegal markets such as the timber/logging market or the counterfeit/smuggled goods market. In this paper, specifically, we apply this general framework to analyze violence in the illegal gold market. For ease of comprehension, we first describe briefly our theoretical implications in the context of the gold market in Brazil. Then, we formalize this as a general equilibrium model, using the gold market as reference.

**3.1. Conceptual overview**  On the gold sell-side, given gold prices, local official stores (*PCOs*) choose to buy gold from either legal or illegal origins. The main advantage of buying illegal gold is that it is probably cheaper than the legal alternative, because illegal gold-mining does not need *PLG* mining permits provided by the federal government. Obtaining these permits can be quite costly, since the approval process may take several years - as recently pointed by federal fiscal auditors at the Tribunal de Contas da União –

ouro-ilegal-lobby-do-garimpo-tem-apoio-do-governo/.

TCU (Court of Auditors)[12]. Of course, lower prices in the illegal gold market may come with potential extra costs associated with law enforcement raids against illegal activities, which depends on the government's ability to monitor miners and *PCOs*.

On the gold-production side, *garimpeiros* decide to enter and mine gold in legal or illegal territories. This decision depends on both the demands for legal and illegal gold by the *PCOs* and the probability of suffering sanctions from the government. Again, choosing to produce gold illegally instead of legally can be a better option for *garimpeiros*, as they do not have to go through the long, bureaucratic process of obtaining permits.

The new regulation, by exempting *PCOs* from liability for not reporting illegal gold-mining, reduces the latter's risk of being punished for transacting illegal gold and thus encourages *PCOs* to do so more often. Hence, the law reduces the government's monitoring capacity, as authorities can no longer trust the *PCOs* to do their screening job accurately. Now, it is as if the government must monitor a pulverized group of *garimpeiros*, instead of collecting information from a much smaller number of *PCOs*. Additionally, the new regulation allowed other people that are not directly involved in mining operations to sell gold to *PCOs*. This creates space for agents operating in other illegal markets, such as drug dealing, to start using gold permits to launder money.

Thus, under the new regulation, we expect *PCOs* to change the composition of their gold purchases towards illegal producers, since their sanction costs for doing so are reduced. Moreover, this effect is intensified by the fact that other agents, besides the *PCOs*, start demanding illegal gold to launder money from other criminal activities. Ultimately, this boosts demand for illegal gold and thus encourages more *garimpeiros* to explore territories where mining is forbidden.

Consequently, we expect an increase in both the competition for illegal mining sites, for which property rights are poorly defined, and in the development of other criminal activities that use gold as a means to money laundering. The ultimate result is more violent disputes over gold with poorly defined property rights.

**3.2. Theoretical Model** Let the gold industry be composed by two markets: the *upstream market*, i.e. *garimpeiros* mining legal and illegal gold deposits; and the *downstream market*, i.e. the *PCOs* buying gold from *garimpeiros* and selling it to the financial sector.

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[12] The court claims that the *National Mining Agency* (Agência Nacional de Mineração - ANM) is too slow in evaluating and issuing gold-mining permits to *garimpeiros*, the *PLG*. For instance, there have been requests that took up to 27 years to be completed. More information about TCU's audit is available at https://portal.tcu.gov.br/imprensa/noticias/tcu-verifica-demora-no-processo-para-a-permissao-de-lavra-garimpeira-plg.htm

*3.2.1. Downstream Market:* The *PCOs* decide how much gold they will buy from legal and illegal suppliers (*garimpeiros*) given the prices, the probability of being caught buying illegal gold ($\mu \in [0, 1]$) and the fine charged by unit of apprehended gold ($\gamma$), as displayed below:

$$\max_{Y_I, Y_L} p(Y_L^\alpha Y_I^{1-\alpha}) - p_L Y_L - [\mu(p_I + \gamma)Y_I + (1 - \mu)p_I Y_I] \qquad (1)$$

Where $p$ is the gold price when selling to the financial sector, $p_I$ is the price of illegal gold paid to *garimpeiros*, and $p_L$ is the price of legal gold paid to *garimpeiros*. $Y_I$ and $Y_L$ are the total amount of illegal and legal gold the *PCO* buys, and $0 < \alpha < 1$ will determine the share of each type of gold to be later sold to the financial sector. Note that the *PCO* sells at the same price $p$ a combination of illegal and legal gold given by a Cobb-Douglas production function with constant returns to scale. This means the final gold-buyer buys a single gold product, not knowing whether its components come from legal or illegal mines.

Additionally, the price *PCOs* pay for each unit of legal gold is simply the price of legal gold $p_L$; whereas the price of illegal gold is an expected value depending on whether the *PCO* is caught doing an illegal transaction or not. After buying illegal gold, the PCO is found guilty with probability $\mu$ and must pay an additional fine to federal authorities equal to $\gamma$ per unit of apprehended gold. Alternatively, authorities do not find irregularities with probability $(1 - \mu)$ and the *PCO* only pays price $p_I$ with no fine.

Solving the maximization problem above gives the following expressions for equilibrium prices.

$$p_I = p(1 - \alpha) \left( \frac{Y_L}{Y_I} \right)^\alpha - \mu\gamma \qquad (2)$$

$$p_L = p\alpha \left( \frac{Y_L}{Y_I} \right)^{\alpha - 1} \qquad (3)$$

Notice that the higher the fine $\gamma$ or the probability of getting caught $\mu$, the less *PCOs* are willing to pay for illegal gold.

*3.2.2. Upstream Market:* Each *garimpeiro* - or cooperative of *garimpeiros* - $g$ in a municipality $m$ decides first whether she will request a gold-mining permit and operate legally, or

operate illegally without a permit. On the one hand, if she chooses to operate legally, she must decide how much to mine from deposits in that municipality to maximize profits. On the other hand, if she chooses to operate illegally, she must compete for mining deposits and conquer them before starting the operation. The following decision tree illustrates this process.

Figure 1: *Garimpeiros* Decision Tree
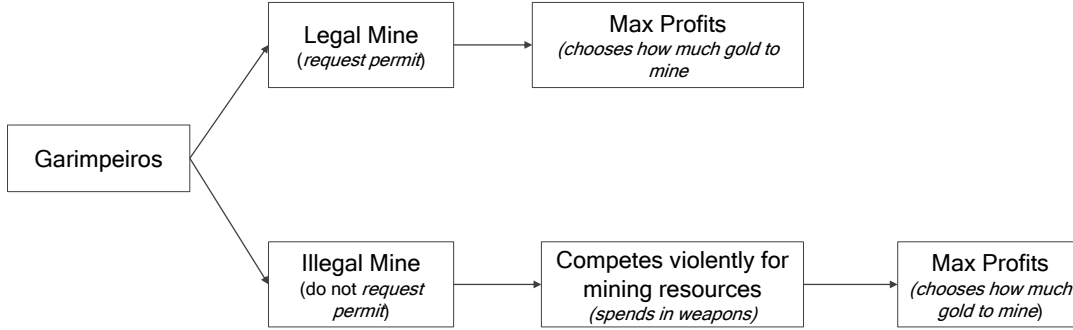


Because of the sequential nature of these decisions, we find the equilibrium of this problem by backward induction, starting with the illegal miners.

*Illegal Miners:* The last decision illegal miners have to make is how much gold to mine from conquered deposits:

$$\max_{y_{g,m,I}} p_I y_{g,m,I} - c(y_{g,m,I}) - k \tag{4}$$

Such that $y_{g,m,I}$ is how much illegal gold the *garimpeiro* $g$ produces at municipality $m$. Costs are determined by function $c(.)$, which we assume to be twice differentiable, increasing and convex; and by fixed costs $k$, such as capital investment in dredging and transporting vessels.

Solving this problem gives the usual solution of marginal revenues equal to marginal

costs, $p_I = c'(y_{g,m,I})$. Rearranging the expression and defining the inverse of cost derivative as the supply function $q(\cdot) = c'^{-1}(\cdot)$, we have the following equilibrium illegal output for *garimpeiro* $g$ at municipality $m$ and her profits:

$$y^*_{g,m,I} = q(p_I) \tag{5}$$

$$\Pi^*_{g,m,I} = p_I q(p_I) - c(q(p_I)) - k \tag{6}$$

Once *garimpeiros* choose the amount of illegal gold to produce, they must now decide how much to spend in weapons $w_{g,m}$ to protect or conquer the mining sites they need. We write this problem as follows, omitting the subscript I for simplicity:

$$\max_{w_{g,m}}\{(p_I y_{g,m} - c(y_{g,m}))s_{g,m} - k - w_{g,m}\} \tag{7}$$

In Equation 7, $s_{g,m}$ is the outcome of a contest function and it determines the proportion of profits that the *garimpeiro* $g$ is able to make when investing $w_{g,m}$ in weapons to secure gold mining sites. This proportion in turn is essentially determined by dividing the expenditure in weapons of *garimpeiro* $g$ by the total investment in weapons of all illegal *garimpeiros*, as shown in Equation 8:

$$s_{g,m} = \frac{w_{g,m}}{\sum_{g' \in G_{m,I}} w_{g',m}} \tag{8}$$

Such that $G_{m,I}$ contains all illegal *garimpeiros* in municipality $m$. Then, the level of violence in $m$ is given by the total expenditures in weapons in municipality $m$, i.e.

$$v_m = \sum_{g \in N_{m,I}} w_{g,m}$$

Replacing $s_{g,m}$ in equation 7 and defining the operational profits as $\Pi^o_{g,m} = p_I y_{g,m} - c(y_{g,m})$ , we re-write the weapon-investing problem of illegal *garimpeiros* as

$$\max_{w_{g,m}}\{\Pi^o_{g,m} \frac{w_{g,m}}{\sum_{g' \in N_{m,I}} w_{g',m}} - k - w_{g,m}\} \tag{9}$$

Assuming *garimpeiros* in municipality $m$ are symmetric, we have the following maximization condition:

$$\frac{N_{m,I}w_{g,m} - w_{g,m}}{(N_{m,I}w_{g,m})^2} = \frac{1}{\Pi^o_{g,m}}$$

Then, isolating $w_{g,m}$ and plugging the equilibrium profits from equation 4 yields the equilibrium investment in weapons for each illegal *garimpeiro* as a function of prices, costs and the number of illegal *garimpeiros* in each municipality:

$$
\begin{aligned}
w^*_{g,m} &= \Pi^{o*}_{g,m} \frac{N_{m,I} - 1}{N^2_{m,I}} \\
&= \{p_I q(p_I) - c(q(p_I))\} \frac{N_{m,I} - 1}{N^2_{m,I}}
\end{aligned}
\tag{10}
$$

Notice that, intuitively, *garimpeiros* invest more on weapons the higher the potential profits from illegal mining sites.

To obtain the equilibrium violence in municipality $m$, since *garimpeiros* are homogeneous, we simply multiply the equilibrium expenditure in weapons $w^*_{g,m}$ by the number of illegal *garimpeiros* $N_{m,I}$, yielding

$$
\begin{aligned}
v^*_m &= \Pi^{o*}_{g,m} \frac{N_{m,I} - 1}{N_{m,I}} \\
&= \{p_I q(p_I) - c(q(p_I))\} \frac{N_{m,I} - 1}{N_{m,I}}
\end{aligned}
\tag{11}
$$

Notice that violence is increasing in the number of illegal *garimpeiros* for all values of $N_{m,I}$. This makes intuitive sense, as more people disputing an illegal mining site would likely lead to more property rights disputes that end up in violence.

Finally, by replacing $w^*_{g,m}$ and $\Pi^{o*}_{g,m}$ in the objective function from equation 9, we obtain the *garimpeiro*'s profits from illegal gold production:

$$
\begin{aligned}
\Pi^*_{g,m,I} &= \Pi^{o*}_{g,m,I} \frac{w^*_{g,m}}{N_{m,I}w^*_{g,m}} - k - w^*_{g,m} \\
&= \Pi^{o*}_{g,m,I} \frac{1}{N_{m,I}} - k - \Pi^{o*}_{g,m} \frac{N_{m,I} - 1}{N^2_{m,I}} \\
&= \frac{1}{N^2_{m,I}} \Pi^{o*}_{g,m,I} - k
\end{aligned}
$$

$$\Pi^*_{g,m,I} = \frac{1}{N^2_{m,I}} \{p_I q(p_I) - c(q(p_I))\} - k \tag{12}$$

Now, we move to the problem of the legal miners. Then, once we have profits for both legal and illegal miners, we can compare them and find the threshold that defines when *garimpeiros* move from one market to the other.

### *Legal Miners:*

Legal miners choose how much gold to produce to maximize profits given the probability of successfully obtaining a mining permit $(1 - \beta)$ and fees to operate legally $(\tau)$, such as permit renewal or submitting environmental reports. Their maximization problem is as follows:

$$\max_{y_{g,m,L}} (1 - \beta)\{p_L y_{g,m,L} - c(y_{g,m,L}) - \tau y_{g,m,L}\} - k \tag{13}$$

Solving the problem above yields a similar first order condition as in Equation 5 and profits as in Equation 6, except for the additional costs associated to obtaining permits and maintaining them:

$$y^*_{g,m,L} = q(p_L - \tau) \tag{14}$$

$$\Pi^*_{g,m,L} = (1 - \beta)\{p_L q(p_L - \tau) - c(q(p_L - \tau)) - \tau q(p_L - \tau)\} - k \tag{15}$$

*3.2.3. Upstream and Downstream markets must clear* In equilibrium, total gold sold to *PCOs* must be equal to total gold mined legally and illegally by all *garimpeiros*. For now, we assume that there is no migration of *garimpeiros* between municipalities, and thus the total population of *garimpeiros* in a municipality is simply the sum of legal and illegal miners:

$$N_m = N^*_{m,L} + N^*_{m,I} \tag{16}$$

Additionally, we normalize the equilibrium price of legal gold such that $p^*_L = 1$. Then, since *garimpeiros* are identical, we can write the market clearing conditions as follows

$$Y_I^* = \sum_m \sum_g y_{g,m,I}^* = N_{m,I}^* q(p_I^*) \tag{17}$$

$$Y_L^* = \sum_m \sum_g y_{g,m,L}^* = (N_m - N_{m,I}^*)q(1-\tau) \tag{18}$$

By plugging the equilibrium totals from Equations 17 and 18 in the prices from Equations 2 and 3, we can write the expression that implicitly gives the optimal price of illegal gold as a function of exogenous parameters. Let us start by the optimal legal prices, which are normalized to 1:

$$p_L^* = p\alpha \left( \frac{Y_L^*}{Y_I^*} \right)^{\alpha-1}$$

$$1 = p\alpha \left( \frac{(N_m - N_{m,I}^*)q(1-\tau)}{N_{m,I}^* q(p_I^*)} \right)^{\alpha-1} \tag{19}$$

$$\frac{1}{p\alpha} \left( \frac{(N_m - N_{m,I}^*)q(1-\tau)}{N_{m,I}^* q(p_I^*)} \right) = \left( \frac{(N_m - N_{m,I}^*)q(1-\tau)}{N_{m,I}^* q(p_I^*)} \right)^{\alpha}$$

We now use this condition to find an expression that implicitly gives the optimal illegal prices from Equation 2.

$$
\begin{aligned}
p_I^* &= p(1-\alpha) \left( \frac{Y_L^*}{Y_I^*} \right)^{\alpha} - \mu\gamma \\
&= p(1-\alpha) \left( \frac{(N_m - N_{m,I}^*)q(1-\tau)}{N_{m,I}^* q(p_I^*)} \right)^{\alpha} - \mu\gamma \\
&= p(1-\alpha)\frac{1}{p\alpha} \left( \frac{(N_m - N_{m,I}^*)q(1-\tau)}{N_{m,I}^* q(p_I^*)} \right) - \mu\gamma \\
&= \frac{(1-\alpha)}{\alpha} \left( \frac{(N_m - N_{m,I}^*)q(1-\tau)}{N_{m,I}^* q(p_I^*)} \right) - \mu\gamma
\end{aligned}
\tag{20}
$$

Finally, we can also find the equilibrium number of illegal miners using the equilibrium profits. To do this, we find the threshold point at which *garimpeiros* are indifferent between operating in legal or illegal gold-mining sites, which happens when profits are the same in both markets. Applying this condition yields the equilibrium number of illegal miners:

$$\Pi^*_{g,m,I} = \Pi^*_{g,m,L}$$

$$\frac{1}{(N^*_{m,I})^2}\{p^*_I q(p^*_I) - c(q(p^*_I))\} - k = (1-\beta)\{p^*_L q(p^*_L - \tau) - c(q(p^*_L - \tau)) - \tau q(p^*_L - \tau)\} - k$$

$$\frac{1}{(N^*_{m,I})^2} = (1-\beta)\frac{\{p^*_L q(p^*_L - \tau) - c(q(p^*_L - \tau)) - \tau q(p^*_L - \tau)\}}{\{p^*_I q(p^*_I) - c(q(p^*_I))\}}$$

$$\frac{1}{(N^*_{m,I})^2} = (1-\beta)\frac{\{q(1-\tau) - c(q(1-\tau)) - \tau q(1-\tau)\}}{\{p^*_I q(p^*_I) - c(q(p^*_I))\}}$$

$$(N^*_{m,I})^2 = \frac{1}{(1-\beta)}\frac{\{p^*_I q(p^*_I) - c(q(p^*_I))\}}{\{q(1-\tau) - c(q(1-\tau)) - \tau q(1-\tau)\}}$$

$$N^*_{m,I} = \sqrt{\frac{\{p^*_I q(p^*_I) - c(q(p^*_I))\}}{(1-\beta)\{q(1-\tau) - c(q(1-\tau)) - \tau q(1-\tau)\}}}$$

(21)

*3.2.4. How does violence change if the level of monitoring $\alpha$ changes?* In this paper, we are interested in the the response of equilibrium violence in municipality $m$ to shocks in the government's monitoring capacity $\mu$, i.e. we would like to know the sign of the partial derivative $\frac{\partial v^*_m}{\partial \mu}$. By differentiating Equation 11 with respect to $\mu$, rearranging terms and using the fact that $q(.) = c'^{-1}(.)$, we get

$$\frac{\partial v^*_m}{\partial \mu} = \frac{1}{(N^*_{m,I})^2}\frac{\partial N^*_{m,I}}{\partial \mu}\{p^*_I q(p^*_I) - c(q(p^*_I))\} +$$
$$+ \frac{N^*_{m,I} - 1}{N^*_{m,I}}[q(p^*_I) - c'(q(p^*_I))q'(p^*_I) + p^*_I q'(p^*_I)]\frac{\partial p^*_I}{\partial \mu}$$
$$\frac{\partial v^*_m}{\partial \mu} = \frac{1}{(N^*_{m,I})^2}\frac{\partial N^*_{m,I}}{\partial \mu}\{p^*_I q(p^*_I) - c(q(p^*_I))\} +$$ (22)
$$+ \frac{N^*_{m,I} - 1}{N^*_{m,I}}[q(p^*_I) - p^*_I q'(p^*_I) + p^*_I q'(p^*_I)]\frac{\partial p^*_I}{\partial \mu}$$
$$\frac{\partial v^*_m}{\partial \mu} = \frac{1}{(N^*_{m,I})^2}\frac{\partial N^*_{m,I}}{\partial \mu}\{p^*_I q(p^*_I) - c(q(p^*_I))\} + \frac{N^*_{m,I} - 1}{N^*_{m,I}}q(p^*_I)\frac{\partial p^*_I}{\partial \mu}$$

To proceed, we need to determine the sign of the partial derivatives in the right-hand side of Equation 22. We start by $\frac{\partial N^*_{m,I}}{\partial \mu}$, which is determined by differentiating Equation 21 with respect to $\mu$.

$$\frac{\partial N^*_{m,I}}{\partial \mu} = \frac{1}{2N^*_{m,I}} \frac{\frac{\partial p^*_I}{\partial \mu}[q(p^*_I) - c'(q(p^*_I))q'(p^*_I) + p^*_I q'(p^*_I)]}{(1-\beta)\{q(1-\tau) - c(q(1-\tau)) - \tau q(1-\tau)\}}$$

$$= \frac{1}{2N^*_{m,I}} \frac{\frac{\partial p^*_I}{\partial \mu}[q(p^*_I) - p^*_I q'(p^*_I) + p^*_I q'(p^*_I)]}{(1-\beta)\{q(1-\tau) - c(q(1-\tau)) - \tau q(1-\tau)\}}$$

$$= \frac{1}{2N^*_{m,I}} \frac{\frac{\partial p^*_I}{\partial \mu}q(p^*_I)}{(1-\beta)\{q(1-\tau) - c(q(1-\tau)) - \tau q(1-\tau)\}} \qquad (23)$$

$$= \frac{\partial p^*_I}{\partial \mu} \frac{q(p^*_I)}{2N^*_{m,I}(1-\beta)g(1-\tau)}$$

Such that $g(1-\tau) = q(1-\tau) - c(q(1-\tau)) - \tau q(1-\tau)$. Then, by plugging 23 in 22 and using $(N^*_{m,I})^2$ from 21 to simplify,

$$\frac{\partial v^*_m}{\partial \mu} = \frac{1}{2N^*_{m,I}(N^*_{m,I})^2} \frac{\frac{\partial p^*_I}{\partial \mu}q(p^*_I)\{p_I q(p_I) - c(q(p_I))\}}{(1-\beta)g(1-\tau)} + \frac{N^*_{m,I}-1}{N^*_{m,I}}q(p^*_I)\frac{\partial p^*_I}{\partial \mu}$$

$$= q(p^*_I)\frac{\partial p^*_I}{\partial \mu}\left[\frac{1}{2N^*_{m,I}} + \frac{N^*_{m,I}-1}{N^*_{m,I}}\right] = q(p^*_I)\frac{\partial p^*_I}{\partial \mu}\left[\frac{2N^*_{m,I}-1}{2N^*_{m,I}}\right] \qquad (24)$$

Because $\left[\frac{2N^*_{m,I}-1}{2N^*_{m,I}}\right] > 0$ for any positive, natural number of illegal miners and $q(p^*_I) \geq 0$, the sign of the derivative hinges on $\frac{\partial p^*_I}{\partial \mu}$. From 20,

$$\frac{\partial p^*_I}{\partial \mu} = \frac{1-\alpha}{\alpha(N^*_{m,I})^2 q^2(p^*_I)}\left[-\frac{\partial N^*_{m,I}}{\partial \mu}q(1-\tau)N^*_{m,I}q(p^*_I)\right] +$$

$$+ \frac{(1-\alpha)}{\alpha(N^*_{m,I})^2 q^2(p^*_I)}\left[-(N_m - N^*_{m,I})q(1-\tau)\left(\frac{\partial N^*_{m,I}}{\partial \mu}q(p^*_I) + N^*_{m,I}q'(p^*_I)\frac{\partial p^*_I}{\partial \mu}\right)\right] - \gamma \qquad (25)$$

Then, plugging 23 in 26 and rearranging terms to isolate $\frac{\partial p^*_I}{\partial \mu}$ finally yields

$$\frac{\partial p^*_I}{\partial \mu} = -\gamma\left[\frac{2(N^*_{m,I})^3(1-\beta)\alpha g(1-\tau)}{2(N^*_{m,I})^3(1-\beta)\alpha g(1-\tau) + (1-\alpha)q(1-\tau)N_M}\right] *$$

$$* \left[\frac{\alpha N^*_{m,I}q^2(p^*_I)}{\alpha N^*_{m,I}q^2(p^*_I) + (1-\alpha)(N_m - N^*_{m,I})q(1-\tau)q'(p^*_I)}\right] < 0 \qquad (26)$$

This means that increasing indirect monitoring of illegal mining activity has a negative effect on the price paid for illegal gold by the *PCOs*. This makes intuitive sense, because higher risk of getting caught by the government increases *PCOs'* perceived cost of acquiring illegal gold. This makes them shift the demand to legal gold, which is safer.

Finally, given $\frac{\partial p_I^*}{\partial \mu} < 0$, we have that

$$\frac{\partial v_m^*}{\partial \mu} < 0 \qquad (27)$$

$$\frac{\partial N_{m,I}^*}{\partial \mu} < 0 \qquad (28)$$

This shows that increasing indirect monitoring capacity affects violence and the number of illegal miners negatively. Hence, our model implies that reducing the government's capacity to monitor illegal miners via *PCOs* has a positive effect on both the size of the illegal gold-mining activity (number of illegal miners) and violent disputes in these illegal mining sites.

With such theoretical implications, we now move to the empirical section to present the data and the reduced form strategy we will use to identify and test the effect of reducing monitoring on illegal activity and violence in illegal gold-mining sites.

## 4. DATA AND DESCRIPTIVES

From the previous sections, our main hypothesis is that decreasing the government's monitoring capacity stimulates illegal gold-mining activities and violence. To test this, we need to combine three large datasets from different sources, containing information on the location of gold deposits, Indigenous Territories and Conservation Areas, and homicides. We describe each of these databases in more detail in the following sub-sections.

**4.1. Gold deposits**  We use a large and publicly available database provided by the Brazilian Geological Service, who is responsible for mapping and analysing all sorts of mineral deposits and rock formations in this country[13]. We specifically use a map of all known mineral deposits in Brazil. Each observation is a geocoded point corresponding to the approximate location of a mineral deposit, its composition, the date it was uploaded in the system, among other characteristics. Since many of these deposits have not yet been explored, however, there is no estimate about the amount of mineral in each observation. Figure 2 shows the spatial distribution of gold deposits versus all other minerals in Brazil.

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[13] http://geosgb.cprm.gov.br

Figure 2: Location of known mineral deposits in Brazil
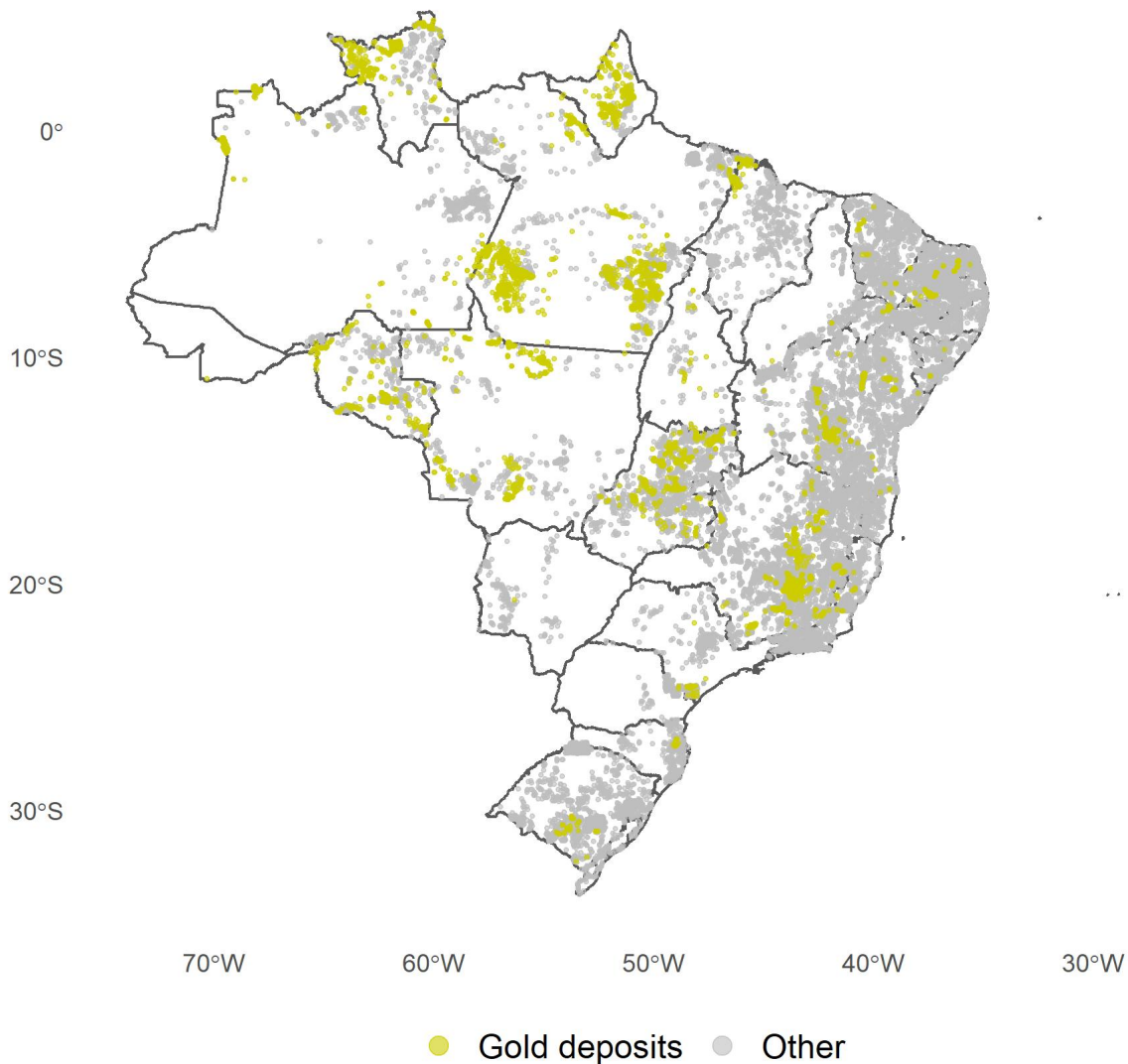


One can see that gold is fairly distributed across the Brazilian territory, with at least one deposit in almost all states. However, there seems to be an over-representation of gold deposits compared with other minerals in the Northwest portion of the country, which corresponds to the Amazon region. Indeed, the Amazon states concentrate around 57% of all known gold deposits in Brazil, as opposed to roughly 14% of all other mineral deposits.

This spatial concentration of gold deposits in the Amazon states is somewhat visible in the official statistics about gold production and permits issued. Output from big mining companies in this region has accounted for 25% of the Brazilian industrial gold production from 2006 to 2017. This does not include gold produced by *garimpeiros*, who have produced roughly 15% of all Brazilian gold in that same period. Unfortunately, the

National Mining Agency (ANM) does not collect micro-level data on gold produced by *garimpeiros*. Nevertheless, tax data[14] suggests that more than 90% of it comes from the Amazon region.

Still on the legal side of this market, we can assess how much *garimpeiros* are interested in exploring gold deposits in the Amazon by looking at the number of permit requests they have made under the *PLG* regime. Figure 3 shows the evolution of these requests over the years, as reported by ANM.

Figure 3: Number of *PLG* gold-mining permit requests in Brazil, from 2006 to 2019
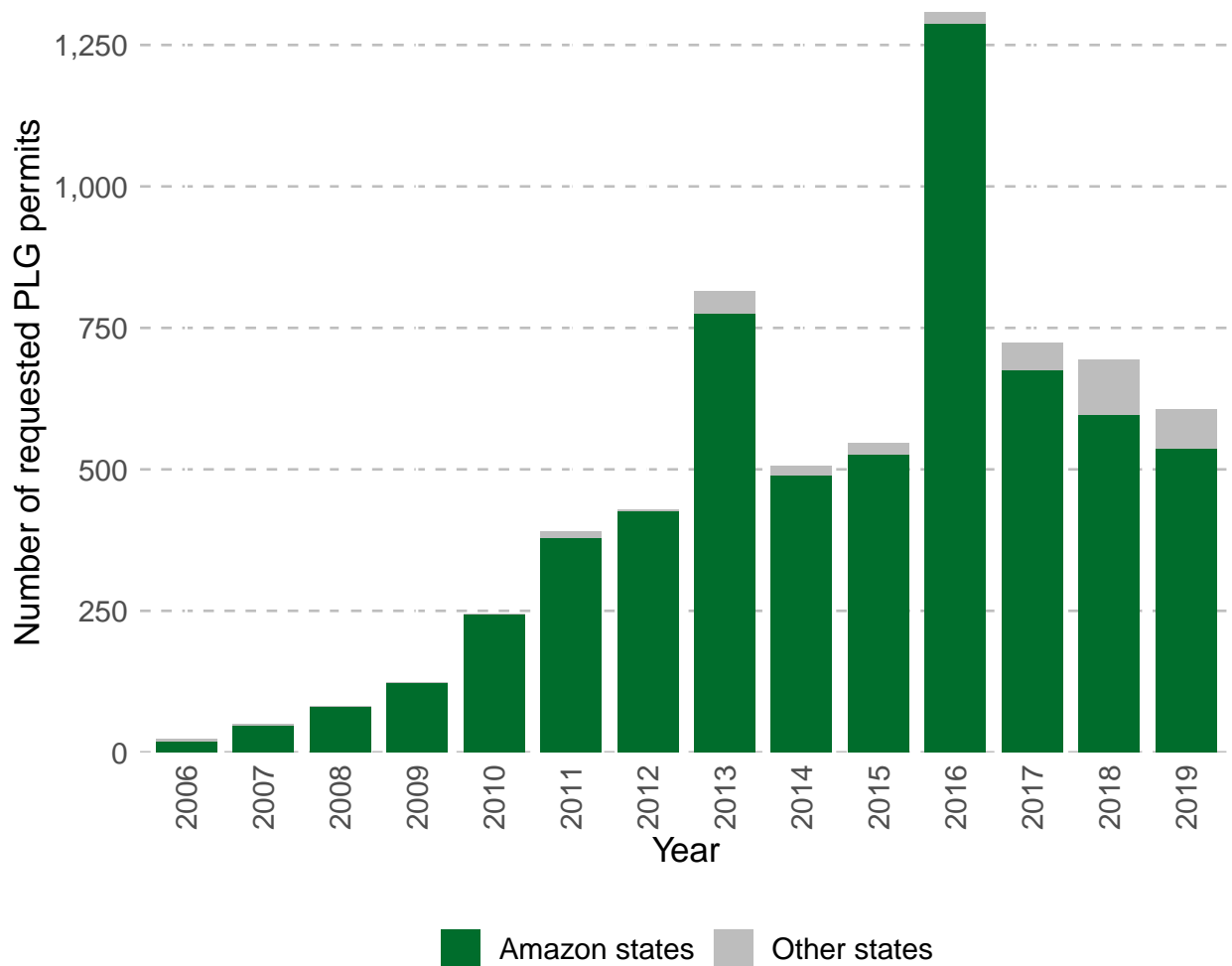


Although permits indicate an "intention-to-explore" **legally**, their spatial pattern suggests that *garimpeiros* are much more likely to mine gold in the Amazon than in anywhere

---

[14] *Garimpeiros* are supposed to pay a federal tax when selling gold to local stores, so one can have an idea of market shares based on the amount of tax paid. Of course, this is likely under-reported due to illegal gold transactions.

else in Brazil. Their increasing interest in gold-mining also seems to respond quite well to the global gold-price boom happening between 2005 and 2012.

**4.2. Indigenous Territories and Conservation Areas**  As much as we can have a sense about the gold market looking at official numbers, we still need to circumvent the lack of data on illegal gold-mining. To do this, we will focus on a prevalent kind of illegal mining that happens when miners explore lands in which their activity is strictly forbidden.

The two main clear-cut cases of areas where mining is illegal are Indigenous Territories and Natural Conservation Areas - both quite widespread in the Amazon region. The first case is protected by the Constitution, which rules that mining in Indigenous Territories is forbidden until Congress regulates this activity with a specific law. Since 1988, this has never happened, and thus all miners working inside these areas are doing so illegally. The second case is protected by Law 9.985/2000, which creates and regulates Unidades de Conservação (UCs) - Natural Conservation Areas. These areas are separated in two categories: Unidade de Conservação de Proteção Integral (UCPI), where no economic activity is permitted; and Unidade de Conservação de Uso Sustentável (UCUS), in which some activities are allowed. From now on, we focus on UCPIs, since it is where mining is clearly forbidden, and we will refer to them simply as Conservation Areas.

It is also noteworthy that the demarcation procedures of these Indigenous Territories and Conservation Areas are quite formalized. Indigenous Territories are defined by FUNAI[15], the federal agency dealing with indigenous affairs, after exhaustive anthropological surveys and subject to presidential approval. Conservation Areas in turn were mainly delimited in the beginning of the 2000's to halt the advance of agriculture, as well as to protect areas of ecological value. We are thus less inclined to believe that these processes are somewhat related to the location of mineral deposits.

Nonetheless, mineral deposits and protected areas incidentally coincide, and even though mining inside them is strictly forbidden, vast anecdotal evidence shows that many *garimpeiros* venture to do so, especially to mine gold. For example, public authorities estimate that 20,000 *garimpeiros* are working inside one single, gold-rich Indigenous Territory with no more than 27,000 indigenous people living in it[16,17]. In Figure 4, we present a

---

[15] Fundação Nacional do Índio.

[16] A federal court has recently ordered these *garimpeiros* to leave the Indigenous Territory, due to increased concern about indigenous people being exposed to outsiders carrying Covid-19. More details available in http://www.mpf.mp.br/regiao1/sala-de-imprensa/noticias-r1/covid-19-trf1-determina-a-retirada-imediata-de-garimpeiros-da-terra-indigena-yanomami.

[17] Still in this same Indigenous Territory, the federal police has closed a large *garimpo* with more than 2,000 people and structure compared to that of a small city, containing markets, restaurants, and even dentists. More details in https://www1.folha.uol.com.br/cotidiano/2021/03/garimpo-fechado-pela-pf-

map of overlapping gold deposits, Indigenous Territories and Conservation Areas in the Amazon region.

Figure 4: Distribution of Indigenous Territories, Conservation Areas, and gold deposits in the Brazilian Amazon region
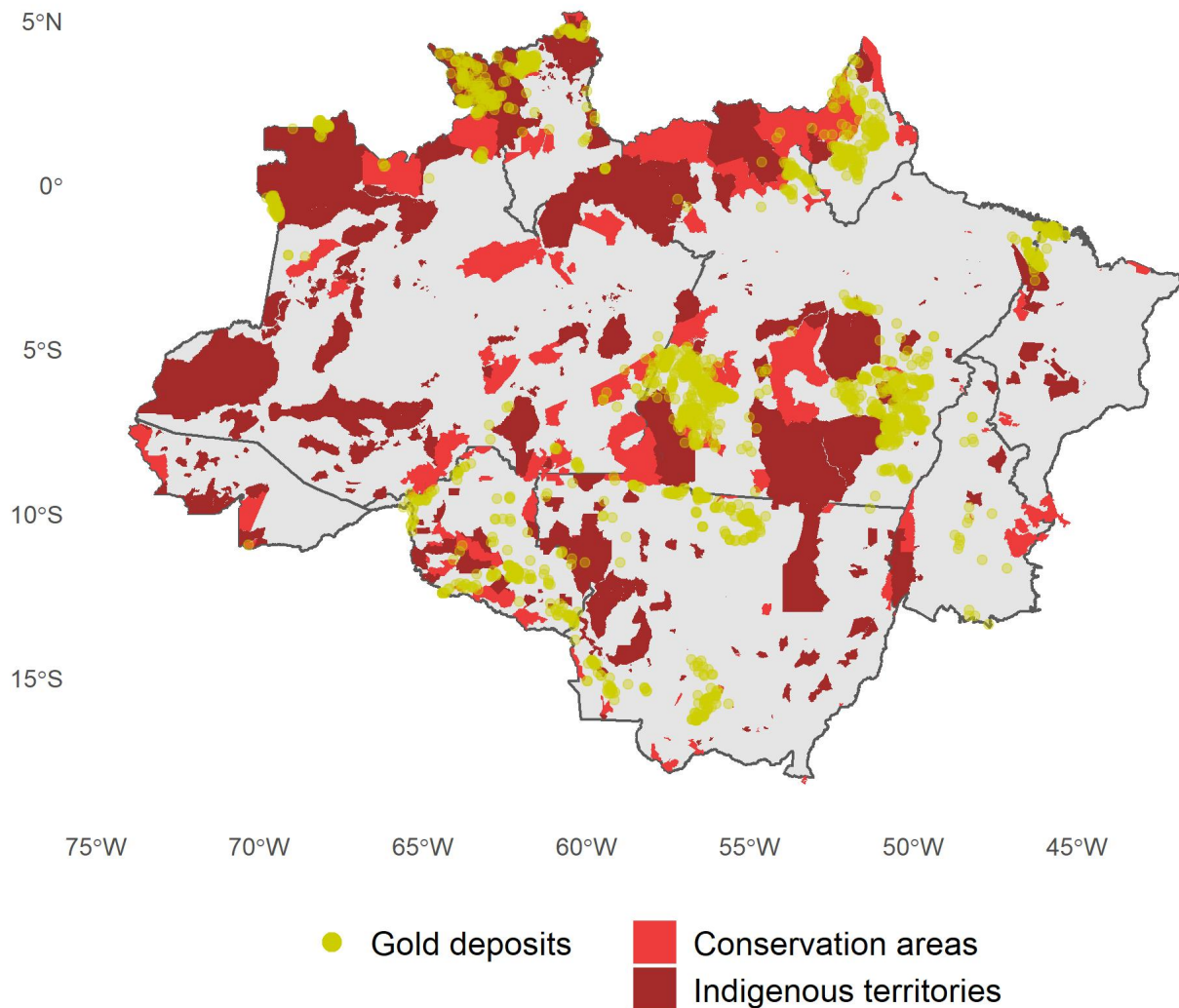


As one may see, a large portion of the Amazon is covered by either Indigenous Territories or Conservation Areas, and thus it is no wonder that part of the gold deposits are located inside them. By overlapping the data, we find that 15.8% of gold deposits in the Amazon are inside Indigenous Territories and 4.2% are inside Conservation Areas.

Furthermore, as a final note, it is not necessarily true that all illegal mining is performed inside these protected areas. Mining may also be considered illegal simply because

em-territorio-yanomami-teve-carnaval-e-bingo-de-revolver.shtml

miners do not have proper permits, regardless of where the deposit is located. Neverthe-less, by merging our protected areas' data with an NGO mapping of illegal mining sites[18], we find that 55% to 84% of illegal gold-mining cases seem to happen inside Indigenous Territories or Conservation Areas.

**4.3.  Violence**  Our main dependent variable is the municipality-year homicide rate per 100,000 inhabitants. To calculate this variable, we obtain the population data by muni-cipality at the Brazilian Institute of Geography and Statistics (IBGE)[19] and obtain the ho-micides data at DATASUS[20]. This last dataset is produced by the Brazilian Ministry of Health's Integrated System of Information, which compiles statistics about mortality and its causes, births, epidemiology, and other data on the Brazilian health system in general.

We categorize homicides using the International Classification of Diseases (ICD-10), maintained by the World Health Organization (WHO), and we consider all deaths by as-sault[21]. Moreover, we also use the ICD-10 classification to create additional explanatory variables to control for urbanization similarly to (Chimeli and Soares, 2017), such as num-ber of deaths by suicide and by traffic accidents[22].

Figure 5 shows the evolution of homicides per 100,000 inhabitants in the Amazon region and compares it to the other federal states. Overall, the Amazon region has be-come increasingly more violent compared with other regions in Brazil. Although violence has strongly declined in 2018 and 2019[23], the homicide rate in the Amazon increased by approximately 60% from 2006 to 2018, whereas it remained quite stable in other regions. Many are the potential reasons for this. For instance, a recent report by the Human Rights Watch argues that an important part of murders in the region is associated to illegal de-

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[18] NGO Rede Amazônica de Informação Georreferenciada makes publicly available a geocoded dataset of illegal mining sites in the Amazon forest. They collect this information by analysing satellite imagery, official police raids against miners, and news pieces about illegal mining. More information is available at https://www.amazoniasocioambiental.org/pt-br.

[19] We combine information from Census and Population Estimates. All the information is available at: https://sidra.ibge.gov.br/

[20] http://www2.datasus.gov.br/

[21] The assault mortality group in ICD-10 (X91-Y09) includes, amongst others, the following specific ca-tegories: X91 - Assault by hanging or choking, X92 - Assault by drowning and submersion, X93 - Assault firing handgun, X94 - Assault by firing firearm of larger caliber, X96 - Assault by use of explosive material, X97 - Assault by use of smoke, fire and flames, X99 - Assault by use of sharp or penetrating object, Y03 - Assault by motor vehicle impact, Y04 - Assault by means of physical force, Y05 - Sexual assault. Details can be found at: http://www2.datasus.gov.br/

[22] Deaths by traffic accidents are in categories V01-V99; Deaths by suicide are in categories X60-X84. More precise information about these specific categories can be found at: http://www2.datasus.gov.br/

[23] The sharp decrease in homicides in Brazil in 2019 is explained in the following arti-cles: https://blogdoibre.fgv.br/posts/o-que-pode-explicar-queda-de-homicidios-no-brasil-em-2019; https://brasil.elpais.com/brasil/2019/09/14/opinion/1568421039_616695.html

forestation[24]. This anecdotal evidence is corroborated by Chimeli and Soares (2017), who show that a regulation prohibiting mahogany logging stimulated violence. Additionally, empirical evidence suggests that violence in the region is associated to land disputes and the lack of well established property rights (Alston et al., 2000; Fetzer and Marden, 2017). Other explanations associate violence to the increasing urban population caused by infrastructure projects such as new roads and hydroelectric power plants, which were not followed by an improvement in the socioeconomic situation in the region. Quite the opposite, they stimulated illegal violent activities such as drug trafficking[25].

Figure 5: Homicides per 100,000 inhabitants - Amazon vs. other regions
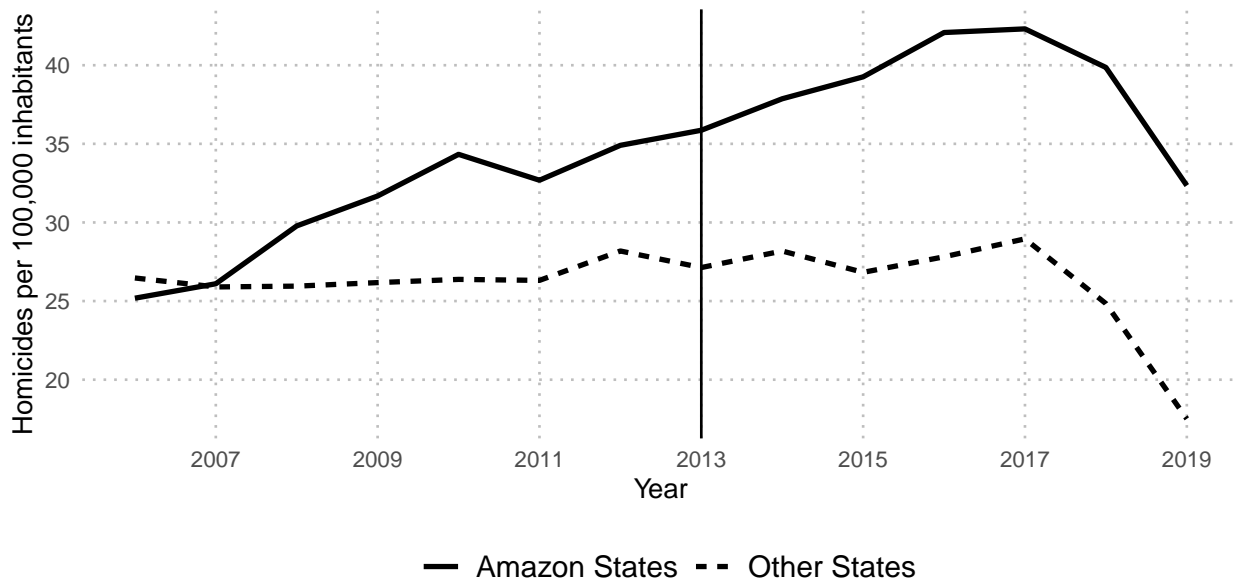


Besides these factors, in this paper we discuss another source of violence, still rather unexplored. We argue that the illegal gold mining activity - fuelled by the new regulation - partially explains the increase in violence observed after 2012. We can see preliminary evidence of this in Figure 6. It shows the relationship between violence and the gold mining activity in the Amazon region by splitting the evolution of homicide rates according to the type of gold deposits available in each municipality. More specifically, we look at

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[24] According to the report (https://www.hrw.org/report/2019/09/17/rainforest-mafias/how-violence-and-impunity-fuel-deforestation-brazils-amazon): "More than 300 people have been killed during the last decade in the context of conflicts over the use of land and resources in the Amazon — many of them by people involved in illegal logging — according to the Pastoral Land Commission (...)"

[25] According to (Machado, 2001): "Institutional crisis, a clientelistic political system, and a growing gap between a formal regime and the political and economic reality are some of the social conditions that breed violence; however, capture of individuals and institutions by drug trafficking networks increases the level of violence and "organizes" its use."

the following groups of municipalities: (i) without gold deposits; (ii) with gold deposits **outside** Indigenous Territories and Conservation Areas (legal gold deposits); (iii) and with gold deposits **inside** Indigenous Territories or Conservation Areas (illegal gold deposits).

Figure 6: Homicides per 100,000 inhabitants in the Amazon region - by gold deposits availability
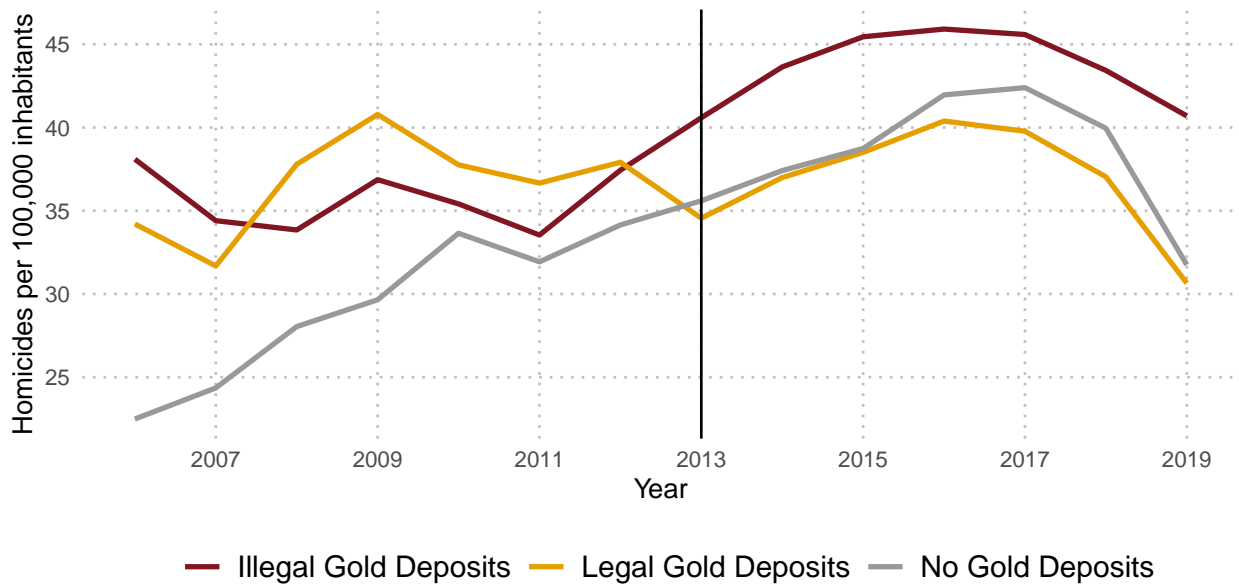


Some interesting patterns appear in Figure 6. First, looking at the grey line, one observes an overall, persistent and positive trend in violence that is not associated with gold mining activity, corroborating the evidence that suggests that there are multiples causes to it in the region. Second, although other factors may be responsible for the upward slope in homicides, the red and yellow curves show that gold mining seems to be associated with more homicides per 100,000. Indeed, until 2012, municipalities with gold deposits had a much higher homicides rate than the others. Finally, we observe the homicides rate in the group of municipalities more prone to illegal gold mining, represented by the red curve, diverging from the others around 2013, precisely when the regulatory change happened.

To check whether this pattern was caused by the regulatory change, we move to the next session to explain in detail how we explore the heterogeneous distribution of gold deposits and protected areas in our identification strategy.

## 5. EMPIRICAL STRATEGY

We propose a difference-in-differences estimator to verify whether the reduction in governmental capacity to enforce the prohibition of selling gold extracted from illegal

mining sites affected violence in municipalities more exposed to illegal mining disproportionately.

The implicit hypothesis in this strategy, as presented in the conceptual framework session, is that the regulatory change, which exempted first-buyers from reporting potentially illicit gold, made it harder for the government to monitor the origin of gold produced by *garimpeiros*. The gold-buyers, responding to the lower probability of getting caught when transacting illegal gold, are consequently stimulated to buy more of it. This increases demand and encourages more miners to work illegally inside protected areas. In turn, the disputes for illegal mining sites, for which there is no enforcement of property rights, increases and ultimately leads to more violent outcomes. Therefore, the regulatory change should lead to more homicides in those municipalities more exposed to illegal mining.

The timing of the regulatory change we explore is the same for all municipalities in the Amazon region. Hence, identification comes from interacting this shock with the plausibly exogenous location of gold deposits across areas where mining is prohibited or not. Indeed, since the location of gold deposits is the result of millions of years of geological formation, it is certainly exogenous to any violence outcome. Furthermore, the ratification of Indigenous Territories and Conservation Areas, although subject to some policy and local discretion, should occur mainly as a result of the presence of Indigenous communities and important ecosystems. Moreover, according to Imazon, the creation of Indigenous Territories in the Amazon occurred more intensely in the 90's whereas the creation of Conservation Areas concentrated in the 2003-2006 period. [26] Hence, the mutual presence of gold deposits and protected areas, which we use to define municipalities exposed to illegal gold-mining sites, should be exogenous to any violence outcome.

Our main specification estimates the following regression, which gives the differential effect of the regulatory change in municipalities that are more and less exposed to illegal gold mining.

$$
\begin{aligned}
Homicides_{it} = {} & \delta_1 GD_i + \delta_2 IGD_i + \delta_3 D_{t \geq 2013} + \\
& + \delta_4 GD_i * D_{t \geq 2013} + \delta_5 IGD_i * D_{t \geq 2013} + \\
& + \delta_6 GD_i * IGD_i * D_{t \geq 2013} + X'_{it}\rho + \mu_{it}
\end{aligned}
\tag{29}
$$

Such that $Homicides_{it}$ indicates the homicide rate per 100,000 people in the municipality $i$ in year $t$; $GD_i$ stands for Gold Deposits and it is a dummy variable indicating whether the municipality $i$ has any gold deposits; $IGD_i$ stands for Illegal Gold Deposits

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[26] https://imazon.org.br/areas-protegidas-na-amazonia-brasileira-avancos-e-desafios-2/

and it is a dummy variable indicating whether the municipality $i$ has any gold deposits located inside Indigenous Territories or Conservation Areas; $D_{t \geq 2013}$ is a dummy variable indicating the period after the change in regulation; $X_{it}$ is a vector of control variables that includes the log of municipal GDP per capita, the participation of agriculture on GDP, the number of deaths by suicide per 100,000 people, and the number of deaths by traffic accidents per 100,000 people.

In equation 29, one should notice that, since a municipality must have at least one gold deposit ($GD_i = 1$) to have potentially illegal mining sites ($IGD_i = 1$), the triple interaction $GD_i * IGD_i * D_{t \geq 2013}$ is omitted from the estimated model. Moreover, we are interested in $\delta_5$, which is the differential effect of the change in regulation for municipalities more exposed to illegal gold-mining activity, conditional on having gold deposits. From our theoretical implications, we expect $\delta_5$ to be statistically different from zero and **positive**, i.e. the regulatory change caused an increase in violence in places exposed to illegal gold mining.

Equation 29, however, reflects the average effect of the change in regulation over all years after 2013. Since we would also like to see how the effect evolved over time, we analyze yearly effects by estimating the regression in Equation 30 as well, where $S$ is the set of years from 2006 to 2019.

$$
\begin{aligned}
Homicides_{it} = \theta_1 GD_i + \theta_2 IGD_i + \sum_{\substack{s \neq 2012}}^{s \in S} \xi_s * 1\{s = t\} + \\
+ \sum_{\substack{s \neq 2012}}^{s \in S} \psi_s GD_i * 1\{s = t\} + \\
+ \sum_{\substack{s \neq 2012}}^{s \in S} \lambda_s IGD_i * 1\{s = t\} + X'_{it}\phi + \varepsilon_{it}
\end{aligned}
\tag{30}
$$

In equation 30, we are interested in all the estimates for $\lambda_s$ and we expect that each one should be positive and statistically significant for the 2013-2019 period.

A first potential concern with our empirical strategy is that gold deposits and protected areas might be spatially concentrated in some specific region in the Amazon where violence is increasing as a response to other factors that we do not control for. In this case, our estimates would be subject to omitted variables bias. Take the state of Pará, for example. It seems that it concentrates more gold deposits in protected areas than other Amazon states, such as Acre. Now, suppose that the increase in violence, observed in

the state of Pará after the change in regulation, was a consequence of the expansion of the agriculture frontier from a neighboring state, such as Mato Grosso. This is a reasonable hypothesis, since violence in the Amazon is also associated with the land disputes caused by the expansion of agriculture (Sauer, 2018; Alston et al., 2000). In this case, we would overestimate the effect of the change in regulation in municipalities more exposed to illegal mining. To control for this, we add alternative specifications incorporating state-specific time dummies.

A second potential concern is that the covariates we use to control for the degree of urbanization and economic development in the municipal level ($X_{it}$ vector) may be correlated to the illegal mining indicator. For example, more illegal mining - and thus more illegal gold laundering - in a specific municipality-year may contribute to an increase in municipal GDP in that year [27]. To overcome this potential issue, we include the interaction of time dummies with the fixed level of each covariate in the first year prior to the sample period (2005) instead of their contemporaneous values, which also allows for a more flexible set of controls.

A third potential concern is that we may be interpreting our estimates as the effect of the new regulation when, in fact, the increase in violence may be the result of other factors that encouraged *garimpeiros* to explore forbidden areas looking for minerals **other than gold**. We argue that if this is the case, then we should observe more violence in municipalities exposed to illegal mining of other types of minerals that operate under the same *PLG* permit system as gold; moreover, such increase in violence should be simultaneous to the new regulation implemented in 2013. In section 7, we present evidence that this is not the case.

Besides these robustness checks, we would also like to verify whether the mechanism behind increasing violence is indeed the intensification of illegal gold-mining inside protected areas. Hence, in section 7, we provide two additional empirical tests. First we verify if, after the regulation change, the deforestation measured by satellite imagery from the Brazilian Space Agency (INPE) increased more in protected areas with gold deposits. Second, we analyze if these places experienced a larger increase in the number of mining-related environmental crimes after the regulatory change. These are direct measures of illegal activity, and finding evidence of more deforestation and environmental crimes provide a lower bound to the increase in the number of illegal *garimpeiros* - or in the intensity of illegal gold-mining - inside protected areas.

Before we proceed to the results, Table 1 shows a brief quantitative description of the

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[27] According to Ministério Público Federal (2020), page 96, in the mining regions of the Amazon, many products and services are priced and payed in gold.

three groups of municipalities in our sample.

Table 1: Descriptive statistics of Brazilian Amazon municipalities according to presence and type of gold deposit, from 2006 to 2012

| | No deposits | Legal deposits | Illegal deposits | ND-ID | LD-ID |
|---|---|---|---|---|---|
| Observations | 622 | 100 | 47 | - | - |
| | [s.e.] | [s.e.] | [s.e.] | [p-value] | [p-value] |
| Population ('000) | 30.2 | 31.5 | 39.4 | -9.2 | -7.9 |
| | [105.1] | [62.2] | [62.4] | [0.0] | [0.1] |
| GDP per capita | 14.3 | 16.0 | 19.2 | -4.9 | -3.2 |
| | [ 15.3] | [ 7.6] | [23.0] | [0.0] | [0.0] |
| % agricultural GDP | 26.5 | 23.0 | 17.8 | 8.7 | 5.2 |
| | [ 14.9] | [13.2] | [16.1] | [0.0] | [0.0] |
| Homicides per 100,000 | 16.0 | 24.4 | 27.0 | -11.0 | -2.6 |
| | [ 20.1] | [23.7] | [27.2] | [0.0] | [0.1] |
| Suicides per 100,000 | 3.5 | 4.0 | 6.1 | -2.6 | -2.1 |
| | [ 7.4] | [ 6.7] | [10.7] | [0.0] | [0.0] |
| Traffic deaths per 100,000 | 19.9 | 24.0 | 19.6 | 0.4 | 4.4 |
| | [ 27.7] | [39.7] | [18.5] | [0.7] | [0.1] |

*Notes:* GDP per capita is in 2019 BRL; standard errors are in brackets; 'No deposits' (ND) are all municipalities without gold deposits; 'Legal deposits' (LD) includes all municipalities with at least one legal gold deposit, but no illegal; 'Illegal deposits' (ID) includes all municipalities with at least one illegal gold deposit; Variables are at the municipality-year level; 'ND-ID' is the mean difference between 'No deposits' and 'Illegal gold deposits'; and 'LD-ID' is the mean difference between 'Gold deposits' and 'Illegal gold deposits'.

One may see that municipalities with at least one gold deposit in protected areas ("Illegal gold deposits"), are mostly different from the municipalities with no gold deposit ("No deposit"), but more comparable to those with some kind of gold deposit ("Gold deposit"). This is expected, since gold-mining is likely to have an impact in variables such as population, GDP per capita and share of agricultural GDP. In any case, these sorts of differences are what we expect to solve by using a difference-in-differences strategy, provided they do not change much during our period of analysis. Nonetheless, in the event they do change, we also add covariates and trends to account for such variations, as described before.

Furthermore, one may notice that there are no significant differences in our dependent variable, homicides rate, between municipalities with illegal deposits and those with legal gold deposits from 2006 to 2012. Because this is an important feature for difference-in-differences, we will come back to this point in more details when we analyze pre-trends.

## 6. Main results

We begin by showing the results for our main specification, as described in Equation 29. In Table 2, we present the effects of the regulatory change on municipalities that are more and less exposed to illegal gold-mining, as well as how they evolve as we add fixed effects and municipal controls.

Table 2: Average treatment effect of legislation change on homicides per 100,000 people in municipalities exposed to illegal gold-mining, from 2006 to 2019

| | Homicides/100,000 people | | | | |
|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) |
| Illegal Gold Dep. * I(Year≥ 2013) | 11.64*** | 11.64*** | 8.47*** | 8.26*** | 8.36*** |
| | (3.36) | (3.36) | (3.19) | (2.98) | (3.22) |
| | | | | | |
| Illegal Gold Dep. | 2.59 | | | | |
| | (3.36) | | | | |
| | | | | | |
| Gold Dep. * I(Year≥ 2013) | −3.72*** | −3.72*** | −0.72 | −1.34 | −0.87 |
| | (1.42) | (1.42) | (1.59) | (1.61) | (1.59) |
| | | | | | |
| Gold Dep. | 8.42*** | | | | |
| | (1.92) | | | | |
| | | | | | |
| I(Year≥ 2013) | 6.14*** | 6.14*** | | | |
| | (0.49) | (0.49) | | | |
| | | | | | |
| Munic. FE | | X | X | X | X |
| State-year FE | | | X | X | X |
| Year FE * Covariates in 2005 | | | | | X |
| Munic. covariates | | | | X | |
| N municipalities | 769 | 769 | 769 | 769 | 769 |
| Observations | 10,766 | 10,766 | 10,766 | 9,228 | 10,766 |
| R² | 0.05 | 0.46 | 0.49 | 0.51 | 0.49 |

*Notes:* (1) No covariates; (2) Includes municipality fixed effects; (3) Includes state-year fixed effects; (4) Includes contemporaneous log of GDP per capita (only available until 2017), share of agricultural GDP, deaths by suicides and deaths in traffic per 100,000; (5) Includes interaction of year fixed effects with municipal covariates' levels from 2005. All errors are clustered at municipal level.*p<.1; **p<.05; ***p<.01

Looking at Table 2, we are interested in the coefficient of the interaction between *Illegal Gold Deposit* and $I(Year \geq 2013)$, which gives us the causal effect of the regulatory change on violence in municipalities exposed to illegal gold deposits, conditional on having any gold deposit. Indeed, the first row in Table 2 shows us that municipalities more

exposed to illegal gold-mining experienced an increase in their homicides rate compared with municipalities exposed to gold-mining in general[28]. This is consistent with our hypothesis that the regulatory change in 2013 encouraged *garimpeiros* to compete more in illegal gold markets, where property rights are weak, which in turn led to more violent disputes.

Moreover, as expected, this is not happening in municipalities exposed to gold-mining in general. By looking at the interaction between *Gold Deposits* and $I(Year \geq 2013)$, we see that municipalities with at least one gold deposit - legal or illegal - observe, if anything, a reduction in violence. This could be associated to a migration from legal mining in one place to illegal mining in another. Alternatively, it could be the effect of increasing income in gold-mining regions, since the negative coefficient fades away when we include state-year fixed effects.

In any case, the positive effect of illegal deposits and the null effect of gold deposits in general reinforce our hypothesis that the law encouraged more illegal gold-mining, which then led to more violent conflicts in places where gold is more likely to be explored illegally.

We now proceed to analyzing the yearly behavior of the effect we estimate in Table 2. This is an important step because of two reasons. First, we need to check whether there are different pre-trend in the dependent variable across our groups of municipalities. Second, we can see which periods are more relevant to the average increase in homicides rate. Figure 7 allows us to assess these two points by showing the yearly incremental number of homicides per 100,000 people in municipalities with at least one illegal gold deposit versus all municipalities with at least one gold deposit. The specification presented here is the one in Column (5) of Table 2[29]

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[28] Appendix A.1 shows the average effect for all municipalities with at least one gold deposit, regardless of whether it is inside a protected area or not.

[29] For the unconditional event study, please refer to Appendix A.2.

Figure 7: Average difference in homicides per 100,000 between municipalities more and less exposed to illegal gold-mining among those with gold deposits, from 2006 to 2019, with full set of controls (95% c.i.)
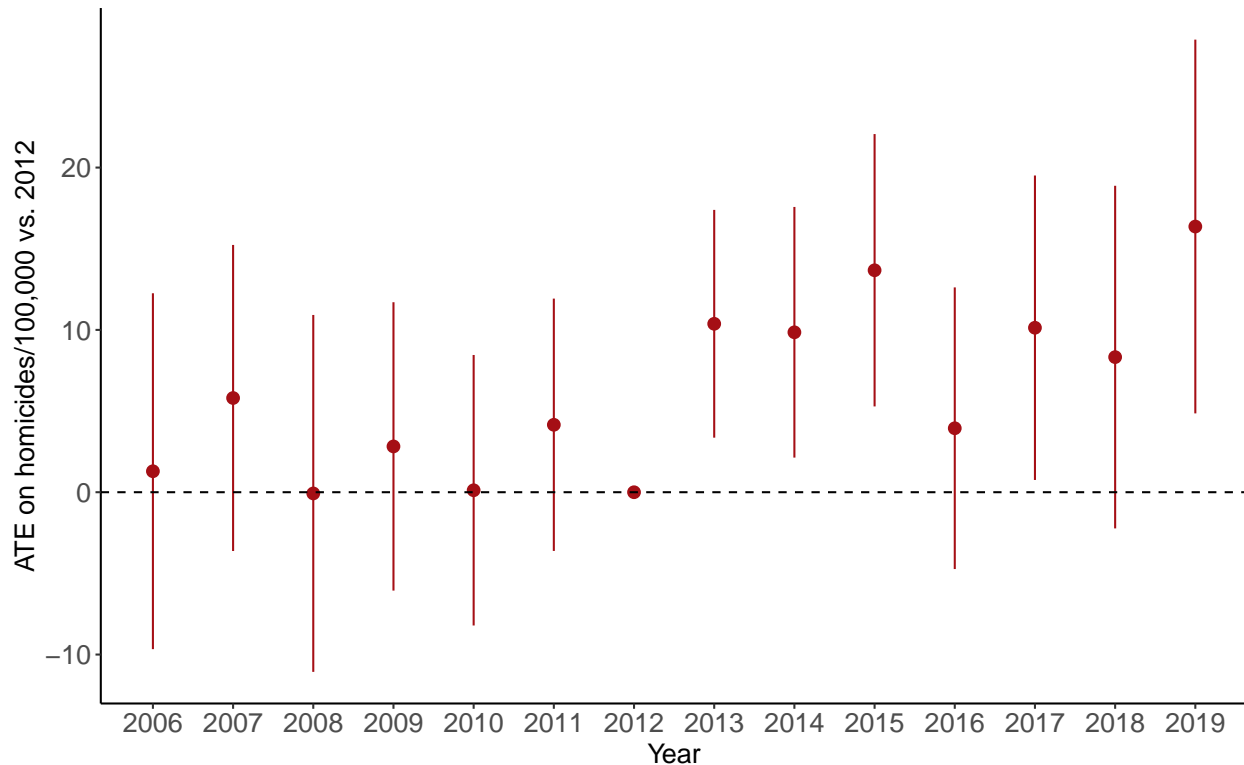


We notice that, before the law came in effect in 2013, there are no significant differences between municipalities more exposed to illegal mining and those less exposed. There also does not seem to be a noticeable trend in the point estimates of each year prior to 2013, which makes us more confident about our identification strategy.

We also remark that point estimates are consistently positive from 2013 to 2019 and are significant for most of the years in this period, indicating that the change in legislation seems to have had an enduring effect on violence in municipalities where illegal gold-mining is more prevalent.

Additionally, we test a logarithmic transformation of the dependent variable both to check whether results depend on functional form and to assess the effect of the law on the percentage change in the homicide rate. However, because the homicide rate can contain zeros, we restrict ourselves to positive observations of homicides per 100,000. This will give us a sense of the intensive margin of our main effect, as shown in Table 3.

Table 3: Average treatment effect of legislation change on (log) homicides per 100,000 people in municipalities exposed to illegal gold-mining, from 2006 to 2019

|  | (log) homicides/100,000 people | | | | |
|---|---|---|---|---|---|
|  | (1) | (2) | (3) | (4) | (5) |
| Illegal Gold Dep. * I(Year≥ 2013) | 0.28*** | 0.28*** | 0.19** | 0.20** | 0.19** |
|  | (0.09) | (0.09) | (0.09) | (0.08) | (0.09) |
| Illegal Gold Dep. | −0.04 | | | | |
|  | (0.12) | | | | |
| Gold Dep. * I(Year≥ 2013) | −0.07 | −0.10** | 0.01 | −0.01 | 0.01 |
|  | (0.05) | (0.05) | (0.06) | (0.06) | (0.06) |
| Gold Dep. | 0.20*** | | | | |
|  | (0.07) | | | | |
| I(Year≥ 2013) | 0.17*** | 0.23*** | | | |
|  | (0.02) | (0.02) | | | |
| Munic. FE |  | X | X | X | X |
| State-year FE |  |  | X | X | X |
| Year FE * Covariates in 2005 |  |  |  |  | X |
| Munic. covariates |  |  |  | X |  |
| N municipalities | 765 | 765 | 765 | 764 | 765 |
| Observations | 7,826 | 7,826 | 7,826 | 6,618 | 7,826 |
| $R^2$ | 0.03 | 0.54 | 0.57 | 0.60 | 0.58 |

*Notes:* (1) No covariates; (2) Includes municipality fixed effects; (3) Includes state-year fixed effects; (4) Includes contemporaneous log of GDP per capita (only available until 2017), share of agricultural GDP, deaths by suicides and deaths in traffic per 100,000; (5) Includes interaction of year fixed effects with municipal covariates' levels from 2005. Municipality-year observations with zero homicides were excluded. All errors are clustered at municipal level.*p<.1; **p<.05; ***p<.01

As in previous results, the change in regulation has boosted conflicts in areas more exposed to illegal gold-mining. Also as before, point estimates decrease as we add controls at state and municipal level, but remain significant. The advantage of this specification, nonetheless, is that now we can interpret estimated coefficients as the approximate percentage increase in homicides per 100,000 people due to the policy change. In the last two columns, with most controls, results suggest that the 2013 regulation change caused homicide rates to increase - in the intensive margin - approximately 20% in municipalities

with at least one gold deposits inside protected areas.

From the results above, we conclude that the change in regulation in 2013 has caused an increase in the average number of homicides per 100,000 in municipalities more exposed to illegal mining. This suggests that the new law, by making it much harder for the government to monitor illegal activities in the gold-mining sector, has allowed the latter to flourish in municipalities with gold deposits located inside Indigenous Territories and Conservation Areas. In turn, since property rights are not formally guaranteed in an illegal market, violent conflicts have ensued as competition for illegal mining sites intensified.

## 7. Mechanisms and Robustness

**7.1. Mechanism: Is violence coming from increasing illegal activity?** In this paper, we argue - and show this more formally in Section 3 - that the regulatory change in 2013 exempted *PCO*s from accountability for buying illegal gold and thus encouraged *garimpeiros* to explore forbidden territories. This, in turn, boosted dispute for mining sites in the absence of clearly defined property rights, leading to violence. In the previous section, we have demonstrated empirically that the latter effect happens, but we still need to show that the illegal mining activity increased after the regulation.

In this sub-section, we propose to test whether more *garimpeiros* ventured into protected areas after 2013 to mine gold illegally. To do this, we look at two different outcome variables that can measure the level of mining activity. The first one is deforestation measured by sattelite imagery from the Brazilian Space Agency (INPE). The second one is environmental fines issued to illegal miners by the federal department responsible for monitoring environmental crimes (IBAMA).

In the first case, we expect the regulatory change to have increased the level of deforestation in places more exposed to illegal gold-mining, since *garimpeiros* typically have to clear part of the forest to set up their operations and camps. However, according to authorities, these changes in forest cover attributable to mining activity are often small and harder to track. Because of this feature, we use deforestation data from the DEGRAD project by INPE, which was devised to detect subtle changes in forest degradation and alert authorities about areas that are prone to be deforested in the future[30].

In the second case, presumably, the regulatory change only affected screening of *garimpeiros* by *PCO*s at the moment of sale, but not the monitoring of *garimpeiros* by the

---

[30] The minimum area mapped by DEGRAD is 6.25 hectares and the imagery comes mostly from LAND-SAT and CBERS satellites with resolution of 20 to 30 meters.

environmental police, IBAMA, in the mining sites. In such case, if indeed more *garimpeiros* started exploring illegal mining sites after 2013, we should observe an increase in fines issued by IBAMA to these miners - or mining-related infractions committed by them - only in places more exposed to illegal gold-mining.

To test either of these two mechanisms, we propose a slightly modified Difference-in-Differences design, as now we have access to data at a more granular level than before. Now, we are able to geocode deforestation and environmental crimes happening inside each Indigenous Territory and Conservation Area. This means our unit of analysis is no longer the municipality, but the protected areas. Then, the equation we estimate is as follows:

$$Y_{jt} = \beta_1 GD_j + \beta_2 NON\_GD_j + \beta_3 D_{t \geq 2013} +$$
$$+ \beta_4 GD_j * D_{t \geq 2013} + \beta_5 NON\_GD_j * D_{t \geq 2013} + \epsilon_{jt} \tag{31}$$

Such that $Y_{jt}$ denotes either deforested area captured by INPE or number of fines issued by IBAMA to illegal miners inside protected area $j$ in year $t$; $GD_j$ is a dummy equal to 1 if there is at least one **gold deposit** inside area $j$; $NON\_GD_j$ is a dummy equal to 1 if there is any *garimpo* mineral deposit inside area $j$ **except gold**; and $D_{t \geq 2013}$ is the treatment dummy, as before.

In this model, the effect of the regulatory change in 2013 on the number of illegal gold-miners is approximated by the effect on either the level of deforestation or the number of mining-related fines in places more exposed to illegal gold-mining. Hence, we are interested in the coefficient of the interaction $GD_j * D_{t \geq 2013}$. Moreover, we add a dummy for protected areas that have other *garimpo* minerals to control for the presence of **any other** mineral deposit inside protected areas that may affect the level of illegal activity in there.

*7.1.1. Deforestation.* Starting with deforestation, our data comprises yearly geocoded polygons indicating whether an area has observed slight reductions in forest cover. The information ranges from 2007 to 2016, and we overlap these deforestation polygons with Indigenous Territories and Conservation Areas to identify which protected areas where affected. Then, we also merge protected areas with the location of deposits of both gold and other minerals that are also mined by *garimpeiros* to identify those that are more exposed to illegal mining.

As anticipated, our observation units are now the protected areas. In total, we observe

566 protected areas[31], among which 415 are Indigenous Territories and 154 are Conservation Areas. The set of protected areas with gold deposits is 44, whereas the set of those with *garimpo* deposits other than gold amounts to 22 observations. The average deforestation in protected areas amounts to 6.8 square kilometers and the average size of such protected areas is 4,089 square kilometers.

Table 4 shows the results for the regression in Equation 31, with $Y_{jt}$ as the size of deforestation in hectares in protected area $j$ and year $t$. Besides individual, year, and state-year fixed effects, we also add year fixed effects interacted with deforestation in 2007 and size of protected area. The goal is to further control for heterogeneous trends in protected areas with different sizes or levels of previous deforestation.

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[31] Since protected areas extend across states, we divide them into smaller units whenever this happens. Hence, our sample consists of sub-units of the original protected areas that are contained in the same state.

Table 4: Average treatment effect of legislation change on deforestation inside protected areas exposed to illegal gold-mining, from 2008 to 2016

|  | Deforested area (in square km) | | | | |
|---|---|---|---|---|---|
|  | (1) | (2) | (3) | (4) | (5) |
| Gold Dep. * I(Year≥ 2013) | 8.4** | 8.4** | 8.4** | 9.2* | 10.4** |
|  | (3.9) | (3.9) | (3.9) | (4.9) | (5.1) |
| Gold Dep. | −7.8** |  |  |  |  |
|  | (3.2) |  |  |  |  |
| Non-Gold Dep. * I(Year≥ 2013) | 1.4 | 1.4 | 1.4 | −0.7 | 2.5 |
|  | (2.3) | (2.3) | (2.3) | (1.5) | (4.0) |
| Non-Gold Dep. | −5.1 |  |  |  |  |
|  | (3.4) |  |  |  |  |
| Gold Dep. * Non-Gold Dep. * I(Year≥ 2013) | −8.4 | −8.4 | −8.4 | −9.6 | −2.1 |
|  | (10.0) | (10.0) | (10.0) | (11.1) | (10.2) |
| Gold Dep. * Non-Gold Dep. | 21.1** |  |  |  |  |
|  | (9.9) |  |  |  |  |
| I(Year≥ 2013) | −4.1* | −4.1* |  |  |  |
|  | (2.1) | (2.1) |  |  |  |
| Prot. Area FE |  | X | X | X | X |
| Year FE |  |  | X | X | X |
| State-Year FE |  |  |  | X | X |
| Year FE * Covariates in 2007 |  |  |  |  | X |
| N Prot. Areas | 566 | 566 | 566 | 566 | 566 |
| Observations | 5,094 | 5,094 | 5,094 | 5,094 | 5,094 |
| $R^2$ | 0.002 | 0.5 | 0.5 | 0.5 | 0.6 |

*Notes:* (1) No covariates; (2) Includes protected area fixed effects; (3) Includes year fixed effects; (4) Includes state-year fixed effects (5) Includes interaction of year fixed effects with both deforestation in 2007 and size of protected areas. All errors are clustered at protected area level.*$p<.1$; **$p<.05$; ***$p<.01$

From Table 4, we learn that the protected areas that are more exposed to illegal gold-mining are the ones suffering more from deforestation after the regulatory change in 2013[32]. The average effect of illegal gold mining on deforestation of protected areas is about additional 10.4 square kilometers, which is quite large and amounts to about 1,400 soccer fields. This suggests that exempting *PCOs* from liability for acquiring illegal gold

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[32] For pre-trends, please refer to Appendix A.3.

has ultimately led to an increase in the level of illegal gold-mining activity. This supports our model predictions, which imply that the regulatory change would increase the equilibrium number of illegal *garimpeiros*.

*7.1.2. Mining-related environmental crimes.* Besides deforestation, we expect the regulatory change to impact the number of mining-related environmental crimes inside protected areas exposed to illegal gold-mining. To test this, we use information on fines issued for environmental crimes provided by IBAMA. This is a very rich dataset containing date, amount, name of perpetrator, municipality, as well as a detailed description of the crime. In this description, we are able to extract all words related to mining and minerals typically explored by *garimpeiros*, such as gold, diamond, gems etc. Then, we categorize fines as "related to illegal mining activity" whenever they present such keywords[33].

Apart from all the information above, the database also has geographic coordinates for a subset of the fines. We use these geocoded observations to merge fines to the polygons of Indigenous Territories and Protected Areas and aggregate them. Finally, as before, we merge this data to geocoded mineral deposits and then categorize protected areas as "exposed to gold-mining", "exposed to other *garimpo* minerals' mining", or "not exposed".

In the period of our sample, from 2006 to 2019, IBAMA has issued 265,810 fines in Brazil, 40% of which were in Amazon states. After we subset to geocoded observations, we are left with 75,233 fines, which represent 70% of the total fines issued in the Amazon for that period. Finally, when we subset to fines inside protected areas, we reach 2,297 observations, among which 126 are related to mining.

Combining these data sources, we estimate Equation 31 and present the results in Table 5. Even after including all controls, we find that protected areas exposed to illegal gold-mining experience an increasing number of mining-related fines issued by IBAMA. This grants further support to our hypothesis that indeed, after the regulatory change in 2013, more *garimpeiros* ventured inside protected areas to mine gold illegally. With more *garimpeiros* disputing illegal mining sites, more violent disputes ensued, as shown in previous sections.

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[33] A full list of words we use to determine the nature of the environmental crimes follows: garimpo, garimpos, mineracao, mineral, minerais, minerio, garimpagem, garimpeira, minerios, extracao de ouro, extraindo ouro, extrair ouro, mercurio, gemas, diamante, cassiterita, estanho, columbita, niobio, tantalo, volframita, tungstenio, scheelita, rutilo, quartzo, berilio, muscovita, espodumenio, lepidolita, feldspato, mica, ametista, topazio, esmeralda, agata, agua-marinha, granada, jaspe, opala, ambar, jade, lapis-lazuli, perola, rubi, safira, turmalina, turquesa, artigo 63 6.514/08, artigo 45 6.514/08.

Table 5: Average treatment effect of legislation change on mining-related infractions committed inside protected areas exposed to illegal gold-mining, from 2006 to 2019

| | Number of fines (infractions) | | | |
| --- | --- | --- | --- | --- |
| | (1) | (2) | (3) | (4) |
| Gold Dep. * I(Year≥ 2013) | 0.17** (0.07) | 0.17** (0.07) | 0.17** (0.07) | 0.17** (0.08) |
| Gold Dep. | 0.04 (0.02) | (0.00) | (0.00) | (0.00) |
| Non-Gold Dep. * I(Year≥ 2013) | 0.01 (0.02) | 0.01 (0.02) | 0.01 (0.02) | 0.01 (0.02) |
| Non-Gold Dep. | 0.0005 (0.01) | (0.00) | (0.00) | (0.00) |
| I(Year≥ 2013) | 0.0003 (0.004) | 0.0003 (0.004) | (0.00) | (0.00) |
| Prot. Area FE | | X | X | X |
| Year FE | | | X | X |
| State-Year FE | | | | X |
| N Prot. Areas | 566 | 566 | 566 | 566 |
| Observations | 7,924 | 7,924 | 7,924 | 7,924 |
| $R^2$ | 0.02 | 0.20 | 0.20 | 0.21 |

*Notes:* (1) No covariates; (2) Includes protected area fixed effects; (3) Includes year fixed effects; (4) Includes state-year fixed effects All errors are clustered at protected area level.*p<.1; **p<.05; ***p<.01

We also compute a dummy variable equal to one if the protected area had at least one fine in a given year. Then, regressing this dummy against the same explanatory variables gives us an easier interpretation of the results, as it is in terms of probability of mining-related environmental crime measured by fines. Table 6 shows that the regulatory change caused the probability of mining-related crimes inside protected areas to increase 5 percentage points in areas more exposed to illegal gold-mining[34].

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[34] In Appendix A.4, we show pre-trends for both the level and probability of environmental crimes.

Table 6: Average treatment effect of legislation change on probability of illegal mining activities inside protected areas exposed to illegal gold-mining, from 2006 to 2019

| | Probability of illegal mining crime | | | |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| Gold Dep. * I(Year$\geq$ 2013) | 0.05** (0.02) | 0.05** (0.02) | 0.05** (0.02) | 0.05** (0.02) |
| Gold Dep. | 0.01* (0.01) | | | |
| Non-Gold Dep. * I(Year$\geq$ 2013) | 0.01 (0.01) | 0.01 (0.01) | 0.01 (0.01) | 0.01 (0.01) |
| Non-Gold Dep. | 0.002 (0.01) | | | |
| I(Year$\geq$ 2013) | $-$0.002 (0.001) | $-$0.002 (0.001) | | |
| Prot. Area FE | | X | X | X |
| Year FE | | | X | X |
| State-Year FE | | | | X |
| N Prot. Areas | 566 | 566 | 566 | 566 |
| Observations | 7,924 | 7,924 | 7,924 | 7,924 |
| $R^2$ | 0.03 | 0.18 | 0.18 | 0.19 |

*Notes:* (1) No covariates; (2) Includes protected area fixed effects; (3) Includes year fixed effects; (4) Includes state-year fixed effects All errors are clustered at protected area level.*p<.1; **p<.05; ***p<.01

In summary, the illegal mining activity - measured by deforestation and IBAMA fines - increases **only** in protected areas with gold deposits, whereas we see no change in areas with other minerals also explored by *garimpeiros*. This supports our hypothesis that violence increases in illegal gold-mining sites because more *garimpeiros* are disputing them after the regulatory change.

**7.2. Mechanism: Is violence also increasing in other minerals' mining sites?** Another potential concern with our empirical design is that violence might have increased not as as a result of the law, but of other factors that encouraged *garimpeiros* to explore forbidden areas looking for all sorts of minerals, leading to more conflicts. If illegal deposits of these other minerals largely coincide with those of gold, we would not be estimating the effect of reducing government's monitoring capacity, but of a more general increase in illegal activity performed by *garimpeiros*.

To check whether it is truly our proposed mechanism that is operating to increase violence in exposed municipalities, we replicate our difference-in-differences estimation using the location of illegal deposits of other valuable minerals explored by *garimpeiros*, excluding gold. If what we observe is a general trend of more conflicts in illegal mining, then we should see a surge in violence not only where gold deposits coincide with protected areas, but also where those other valuable minerals coincide with the latter.

To do this, we map deposits of minerals that are also operated under the *PLG* permit regime - the same that *garimpeiros* need to obtain to legally explore gold. These minerals are called *minerais garimpáveis* by regulators and were primarily grouped together based on the relative simplicity of their mining process compared with resources like iron or alloy, which require much more capital investment and complex operations. Although, as we have argued, *garimpeiros* are much better equipped and organized today, it still stands that *minerais garimpáveis* are relatively more accessible to and profitable for individual and rudimentary operations, much in the same way as gold[35]. Table 7 shows the result of this exercise.

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[35] The complete list of *minerais garimpáveis* defined by the Brazilian Law follows: diamond, cassiterite, columbite, niobium, tantalum, wolframite, tungsten, scheelite, rutile, quartz, beryllium, muscovite, spodumene, lepidolite, feldspar, mica. The list also includes "other gems" with no specification, and thus we include as many gems as we could find in the mineral deposits government database: amethyst, topaz, emerald, agate, aquamarine, garnet, jasper, opal, amber, jade, lapis lazuli, pearl, ruby, sapphire, tourmaline, turquoise. Finally, some of these minerals are typically components of other substances, such as cassiterite is the main component of tin. As an example, there is no natural occurrence of cassiterite in our database, but tin instead, so we include the latter in the list.

Table 7: ATE of legislation change on homicides per 100,000 people in municipalities exposed to illegal mining of *garimpo* minerals other than gold, from 2006 to 2019

| | Homicides/100,000 people | | | | |
|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) |
| Other Illegal Dep. * I(Year≥ 2013) | 0.88 | 0.88 | −1.11 | 0.09 | −1.29 |
| | (3.67) | (3.67) | (3.52) | (3.30) | (3.51) |
| Other Illegal Dep. | −3.90 | | | | |
| | (3.70) | | | | |
| Other Dep. * I(Year≥ 2013) | −1.84 | −1.84 | −0.71 | −0.94 | −0.67 |
| | (2.27) | (2.27) | (2.24) | (2.39) | (2.25) |
| Other Dep. | 6.67*** | | | | |
| | (2.07) | | | | |
| Illegal Gold Dep. * I(Year≥ 2013) | 11.25*** | 11.25*** | 8.88** | 8.18** | 8.84** |
| | (3.53) | (3.53) | (3.52) | (3.27) | (3.52) |
| Illegal Gold Dep. | 4.35 | | | | |
| | (3.94) | | | | |
| Gold Dep. * I(Year≥ 2013) | −3.92*** | −3.92*** | −0.81 | −1.48 | −0.95 |
| | (1.43) | (1.43) | (1.58) | (1.61) | (1.59) |
| Gold Dep. | 9.16*** | | | | |
| | (1.94) | | | | |
| I(Year≥ 2013) | 6.30*** | 6.30*** | | | |
| | (0.49) | (0.49) | | | |
| Munic. FE | | X | X | X | X |
| State-year FE | | | X | X | X |
| Year FE * Covariates in 2005 | | | | | X |
| Munic. covariates | | | | X | |
| N municipalities | 769 | 769 | 769 | 769 | 769 |
| Observations | 10,766 | 10,766 | 10,766 | 9,228 | 10,766 |
| R² | 0.06 | 0.46 | 0.49 | 0.51 | 0.49 |

*Notes:* (1) No covariates; (2) Includes municipality fixed effects; (3) Includes state-year fixed effects; (4) Includes contemporaneous log of GDP per capita (only available until 2017), share of agricultural GDP, deaths by suicides and deaths in traffic per 100,000; (5) Includes interaction of year fixed effects with municipal covariates' levels from 2005. All errors are clustered at municipal level. *p<.1; **p<.05; ***p<.01

As opposed to the case of gold-mining, once we introduce time-varying controls, we

do not see a significant increase in violence in municipalities with deposits of other *garimpo* minerals (excluding gold) inside Indigenous Territories and Conservation Areas. This suggests that it was really the permissiveness specific to gold transactions introduced by the 2013 legislation that affected violence in municipalities with illegal gold deposits, not some common factor affecting all sorts of illegal deposits that *garimpeiros* explore.

### 7.3. Mechanism: Violence in mining sites and/or in the places of sale (income effect)?

In this paper, our main hypothesis is that violence increased in municipalities that are more exposed to illegal gold-mining because dispute for deposits among *garimpeiros* increases after the regulation changes. However, it is also possible that the spike in homicides per 100,000 in and after 2013 comes from more criminals robbing *garimpeiros* as they go to the *PCO* stores to sell their product. In this case, the legislation would be affecting violence much more via income effect rather than via property rights disputes at mining sites.

To test whether the effect is coming from violence at points of sale, we repeat our difference-in-differences exercise, but this time take into account that some municipalities might concentrate raw gold purchasing activity. Indeed, most transactions of raw gold from *garimpeiros* to *PCOs* happen in three main gold-buying poles in the Amazon states: Itaituba (PA), Peixoto Azevedo (MT), and Poconé (MT), according to the volume of taxes collected from these operations[36] Moreover, they concentrate almost half of all *PCOs* in the Amazon region[37]

In Table 8, we show the results for three different exercises. Column (1) shows the effect of decreasing monitoring on violence in municipalities more exposed to illegal mining, excluding the three largest markets of raw gold in the Amazon region. Of these municipalities, only one - the largest gold-market, Itaituba (PA) - has gold deposits in protected areas. Column (2), in turn, excludes all 23 municipalities that possess at least one *PCO* store - out of which 6 also possess gold deposits in protected areas. Finally, in Column (3) we interact the presence of *PCOs* with the existence of legal and illegal gold deposits. This latter specification should give us the effect of the regulatory change on violence in municipalities more exposed to illegal mining, controlling for whether that municipality is a point of sale or not.

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[36] Between 2006 and 2019, these three municipalities concentrate 67% of *IOF* taxes levied in the Amazon region from *garimpeiros* at the moment they sell raw gold to first-buyers.

[37] The location of all *PCO* stores is reported by the Brazilian Central Bank and is available at https://www.bcb.gov.br/fis/info/agencias.asp?frame=1.

Table 8: Average treatment effect and presence of official gold stores (PCO)

| | Homicides/100,000 people | | |
|---|---|---|---|
| | (1) | (2) | (3) |
| Illegal Gold Deposits. * I(Year$\geq$ 2013) | 8.08** (3.22) | 6.82** (3.28) | 6.78** (3.28) |
| Illegal Gold Deposits. * I(Year$\geq$ 2013) $* I(PCO)$ | | | 10.12 (9.47) |
| Gold Deposits * I(Year$\geq$ 2013) | −1.29 (1.59) | −1.57 (1.69) | −1.37 (1.69) |
| Gold Deposits. * I(Year$\geq$ 2013) $* I(PCO)$ | | | 4.02 (6.04) |
| I(Year$\geq$ 2013) $* I(PCO)$ | | | 1.76 (4.55) |
| N municipalities | 766 | 748 | 769 |
| Observations | 10,724 | 10,472 | 10,766 |
| $R^2$ | 0.49 | 0.48 | 0.49 |

*Notes:* (1) We remove the 3 municipalities with largest gold tax revenues: Itaituba, Pocone, and Peixoto de Azevedo. (2) We remove all municipalities with PCOs. (3) We interact gold deposits with a dummy indicating the presence of PCOs. All models include municipality fixed effects, state-year fixed effects, interaction of year fixed effects with municipal covariates' levels from 2005 (log of GDP per capita, share of agricultural GDP, deaths by suicides and deaths in traffic per 100,000) All errors are clustered at municipal level. *p<.1; **p<.05; ***p<.01

We observe that the main effect only decreases slightly when we exclude the largest markets for *garimpeiros'* gold. Moreover, although it decreases more when we exclude all municipalities with *PCOs*, it is still large and significant. This suggests that the increase in homicides that we observe in municipalities exposed to illegal mining after the change in regulation is really coming from violence at the places of production of gold, where *garimpeiros* dispute for illegal mining sites.

Nonetheless, Column (3) shows an additional interesting result. Although the effects are not significant, it is possible that the presence of *PCOs* also affects violence at the places of sale. This is quite reasonable, since more people are bringing valuable items to these places and are exposed to violent robberies. This does not, however, invalidate our previous hypothesis, but instead complements it by showing another implication of the regulatory change via increasing illegal gold-mining activities.

**7.4. Robustness: effect of regulation on covariates.** One potential alternative story is that violence in municipalities exposed to illegal gold-mining is coming from the fact that this activity draws many social problems to these places, such as drug addiction, suicides, prostitution etc. In such case, violence would come from worsening social conditions rather than disputes for property rights. This possibility should be partially captured by our covariates, but it is still important to check whether municipalities with illegal gold deposits are experiencing different social dynamics than the other. To do this, we repeat

the difference-in-differences exercise, but we now use each of the covariates in our model as a dependent variable, which are meant to measure this sort of dynamics. Table 9 shows our findings.

Table 9: Effect of legislation change on covariates in municipalities exposed to illegal gold-mining, from 2006 to 2019

|  | Suicides | Deaths Traffic | (log) GDP | (%) agric. | (log) pop. |
|  | (1) | (2) | (3) | (4) | (5) |
| Illegal Gold Dep. * I(Year≥ 2013) | −0.61 | −0.21 | −0.05 | 0.14 | −0.02 |
|  | (0.87) | (2.49) | (0.05) | (0.96) | (0.04) |
| Gold Dep. * I(Year≥ 2013) | 0.15 | 1.04 | 0.03 | −0.19 | −0.001 |
|  | (0.53) | (1.90) | (0.02) | (0.62) | (0.01) |
| Munic. FE | X | X | X | X | X |
| State-year FE | X | X | X | X | X |
| Year FE * Covariates in 2005 | X | X | X | X | X |
| N municipalities | 769 | 769 | 769 | 769 | 769 |
| Observations | 10,766 | 10,766 | 9,228 | 9,228 | 10,766 |
| $R^2$ | 0.20 | 0.40 | 0.94 | 0.91 | 0.99 |

*Notes:* (1) Suicides per 100,000 people as dependent variable; (2) Deaths in traffic per 100,000 people as dependent variable; (3) (log) GDP per capita as dependent variable; (4) Share of agricultural GDP as dependent variable; (4) (log) population as dependent variable; All models include municipal fixed effects, year fixed effects, and state-year fixed effects. Each model includes the interaction between year fixed effects and all covariates in 2005, except for the covariate in the left-hand side. All errors are clustered at municipal level.$^*$p<.1; $^{**}$p<.05; $^{***}$p<.01

From these results, there does not seem to be a significant difference in any of those variables after the regulation changes. Moreover, point-wise estimates seem to be small. This suggests that municipalities exposed to illegal gold-mining are not evolving differently, at least in terms or ubanization (measured by suicides and deaths in traffic as in Chimeli and Soares (2017)), GDP per capita, GDP composition (share of agricultural product), or population growth[38].

## 7.5. Robustness: subset to municipalities with protected areas.

Another concern is that our empirical strategy is capturing increasing violence in municipalities that have protected areas. Because the existence of Indigenous Territories and Conservation Areas

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[38] One additional concern is that we are dealing with population estimates for the 2011-2019 period, since there are no Census observations for these years. Please refer to Appendix A.5 for a more detailed discussion about this.

also affects disputes for agricultural land and pastures, it could be that violence increased after 2013 in all municipalities with protected areas. In this case, our model could be capturing, for example, violent disputes for land to be used by the aggro-business sector rather than violent confrontation for illegal mining sites.

In Table 10, however, we see this does not seem to be case. In this exercise, we run our main specification, but now we account for the presence of protected areas in municipalities in two ways: in Column (1), we exclude all municipalities without protected areas; in Column (2), we explicitly model the effect of protected areas on violence with a dummy interacted with the treatment period.

Table 10: Average treatment effect and presence of protected areas (Indigenous Territories or Conservation Areas)

| | Homicides/100,000 people | |
| --- | --- | --- |
| | (1) | (2) |
| Illegal Gold Deposits. * I(Year$\geq$ 2013) | 7.75** (3.47) | 8.02** (3.43) |
| Gold Deposits * I(Year$\geq$ 2013) | −0.59 (2.24) | −1.53 (2.22) |
| Gold Deposits. * I(Year$\geq$ 2013) $* I(Protected)$ | | 1.28 (2.95) |
| I(Year$\geq$ 2013) $* I(Protected)$ | | −0.54 (1.11) |
| N municipalities | 345 | 769 |
| Observations | 4,830 | 10,766 |
| $R^2$ | 0.53 | 0.49 |

*Notes:* (1) We only include in the sample those municipalities with at least one protected area (Indigenous Territory or Conservation Area); (2) We interact the main effects with a dummy indicating whether the municipality has at least one protected area (Indigenous Territory or Conservation Area); All models include municipality fixed effects, state-year fixed effects, interaction of year fixed effects with municipal covariates' levels from 2005 (log of GDP per capita, share of agricultural GDP, deaths by suicides and deaths in traffic per 100,000) All errors are clustered at municipal level. *p<.1; **p<.05; ***p<.01

In both cases, we see that the effect of the regulatory change on violence remains fairly unchanged. Furthermore, we see no significant effect of the presence of protected areas on violence. These results suggest that increasing violence in municipalities exposed to illegal mining is not coming from proneness to land conflicts arising from the mere presence of protected areas.

## 8.  FINAL REMARKS

In this paper, we study the consequences of reducing incentives for downstream players *not* to buy illegal products. We investigate both theoretically and empirically how this affects the size of the upstream illegal market and subsequent violent disputes for goods with poorly defined property rights.

In particular, we show that a legislation change in 2013 affected the government's capacity to monitor illegal gold transactions, reducing the cost of acquiring illegal gold and boosting its demand. This caused violence to explode in the supply side, especially in places exposed to illegal gold-mining, as the model mechanisms suggest. The new regulation, by increasing the number of people that authorities need to screen to find irregularities, encouraged more *garimpeiros* to violently dispute gold deposits located in areas where mining is forbidden.

Using a difference-in-differences design, we show that municipalities with gold deposits in Indigenous Territories or Conservation Areas had a disproportionate increase in homicides per 100,000 people after the law was passed, compared with municipalities with gold deposits outside such areas. We also show that this violence is coming from an increase in the illegal gold-mining activity, as deforestation and mining-related environmental crimes increase more inside those protected areas exposed to illegal gold-mining. We do not see this happening, however, in protected areas without gold or those with other *garimpo* minerals.

These powerful effects associated to changing incentives, however, are often overlooked. In our case, legislators debated for less than 2 minutes in session before approving the amendments that led to the - hopefully - unintended consequences we discussed in this paper. Of course, such rush to change the rules might have been justified by an attempt to increase tax revenues, even at the expense of boosting illegal activities. Nonetheless, it seems this would be a small gain to compensate the unintended increase in homicide rates of nearly 20% across the Amazon's municipalities exposed to illegal gold-mining. Indeed, even assuming that the illegal market was responsible for the entire increase in tax revenues from gold transactions attributable to PCOs across all IGD municipalities[39] in the Amazon region, this would amount to little more than 875 million dollars (2015 values)[40] compared with a total value of lives lost of 1.28 billion dollars in the period after

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[39] Those municipalities exposed to illegal gold mining.

[40] The value of gold tax revenues attributable to PCOs is calculated from Transferências Obrigatórias da União para os Municípios (IOF ouro). The increase in gold revenues tax is computed by taking the difference between all the gold tax revenues received from 2013 to 2019 and those taxes received from 2006 to 2012.

the regulatory change[41].

Furthermore, our analysis also suggests that making local stores liable for buying illegal gold seems more effective to deter this activity and its consequences, such as violent conflict and deforestation, than transferring this responsibility to higher authorities or leaving all the weight to police raid operations in the forest. This is not true only for the gold market in the Brazilian Amazon, but it can also be a solution to deal with other markets in which the legal and the illegal coexist, such as logging, imported goods, cattle raised in illegal pastures etc. In all these cases, encouraging buyers to acquire legal products can propagate benefits upstream.

Finally, our findings raise caution, for example, for governments and companies that institute mechanisms similar to mining permits, such as product certification policies. What we uncover here shows that certification must be coupled with proper verification by frontline buyers, and that this hinges on how accountable the latter are. Stringent certification requirements with no liability for the local buyers are likely to fail and make room for illegal production.

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[41] We assume here an average Value of Statistical Life of 3.29 million Brazilian Reals (approximately 988 thousand dollars in 2015) according to Pereira et al. (2020). Exchange rates are available at http://www.ipeadata.gov.br/ExibeSerie.aspx?serid=31924.

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## A. APPENDIX

**A.1. Effect of regulatory change on all municipalities exposed to gold-mining.** In addition to estimating the separate effect of the regulation, we show here the overall effect of the regulatory change in all municipalities that have at least one gold deposit in it, regardless of whether it is inside protected areas or not. The model we estimate is given by Equation 32.

$$Homicides_{it} = \beta_1 GD_i + \beta_2 D_{t \geq 2013} + \beta_3 GD_i * D_{t \geq 2013} + X'_{it}\gamma + \epsilon_{it} \tag{32}$$

Such that $Homicides_{it}$ indicates the homicide rate per 100,000 people in the municipality $i$ in year $t$; $GD_i$ stands for Gold Deposits and it is a dummy variable indicating whether the municipality $i$ has any gold deposits; $D_{t \geq 2013}$ is a dummy variable indicating the period after the change in regulation; $X_{it}$ is a vector of control variables including the log of municipal GDP per capita, the participation of agriculture on GDP, the number of deaths by suicide per 100,000 people, and the number of deaths by traffic accidents per 100,000 people.

Table 11: Average treatment effect of legislation change on homicides per 100,000 people in municipalities with gold deposits, from 2006 to 2019

|  | Homicides/100,000 people | | | | |
| --- | --- | --- | --- | --- | --- |
|  | (1) | (2) | (3) | (4) | (5) |
| Gold Deposits * I(Year≥ 2013) | 0.01 | 0.01 | 1.81 | 1.13 | 1.59 |
|  | (1.50) | (1.50) | (1.56) | (1.54) | (1.56) |
| Gold Deposits | 9.25*** | | | | |
|  | (1.65) | | | | |
| I(Year≥ 2013) | 6.14*** | 6.14*** | | | |
|  | (0.49) | (0.49) | | | |
| Munic. FE |  | X | X | X | X |
| State-year FE |  |  | X | X | X |
| Year FE * Covariates in 2005 |  |  |  |  | X |
| Munic. covariates |  |  |  | X |  |
| N municipalities | 769 | 769 | 769 | 769 | 769 |
| Observations | 10,766 | 10,766 | 10,766 | 9,228 | 10,766 |
| $R^2$ | 0.04 | 0.46 | 0.49 | 0.51 | 0.49 |

*Notes:* (1) No covariates; (2) Includes municipality fixed effects; (3) Includes state-year fixed effects; (4) Includes contemporaneous log of GDP per capita (only available until 2017), share of agricultural GDP, deaths by suicides and deaths in traffic per 100,000; (5) Includes interaction of year fixed effects with municipal covariates' levels from 2005. All errors are clustered at municipal level.*p<.1; **p<.05; ***p<.01

As expected, Table 11 shows small and non-significant effects for the average municipality exposed to gold-mining. This makes sense, as the permissiveness introduced in the 2013 legislation is not encouraging all gold-mining activity in the Amazon, but only the one performed illegally.

**A.2. Event study chart of main effect without controls.** Figure 8 shows the incremental number of homicides per 100,000 people in municipalities with at least one illegal gold deposit versus all municipalities with at least one gold deposit.

Figure 8: Average difference in homicides per 100,000 between municipalities more and less exposed to illegal gold-mining, from 2006 to 2019 (95% c.i.)
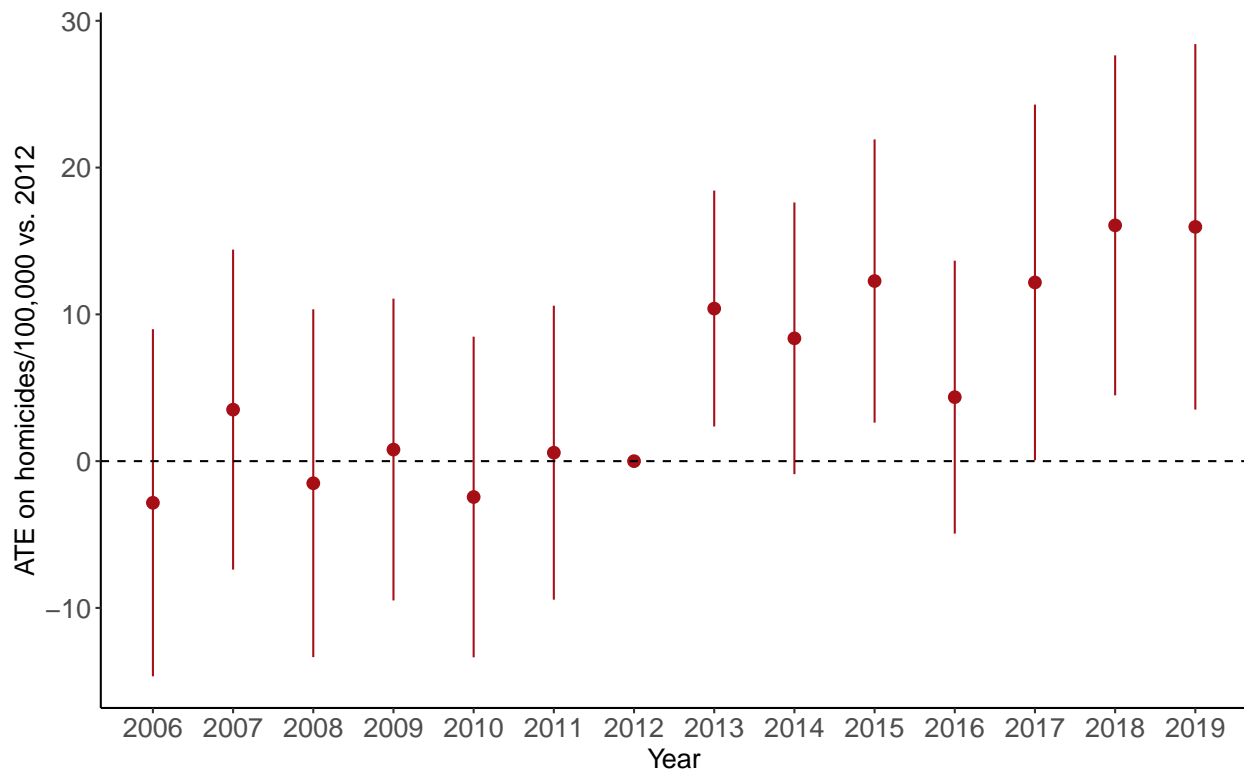


**A.3. Event study of effect on deforestation.** Figure 9 shows the additional effect on the size of deforestation, in square kilometers, for protected areas with at least one gold deposit in them.

Figure 9: Average difference in deforestation (in square kilometers) between protected areas more and less exposed to illegal gold-mining, from 2006 to 2019 (95% c.i.)
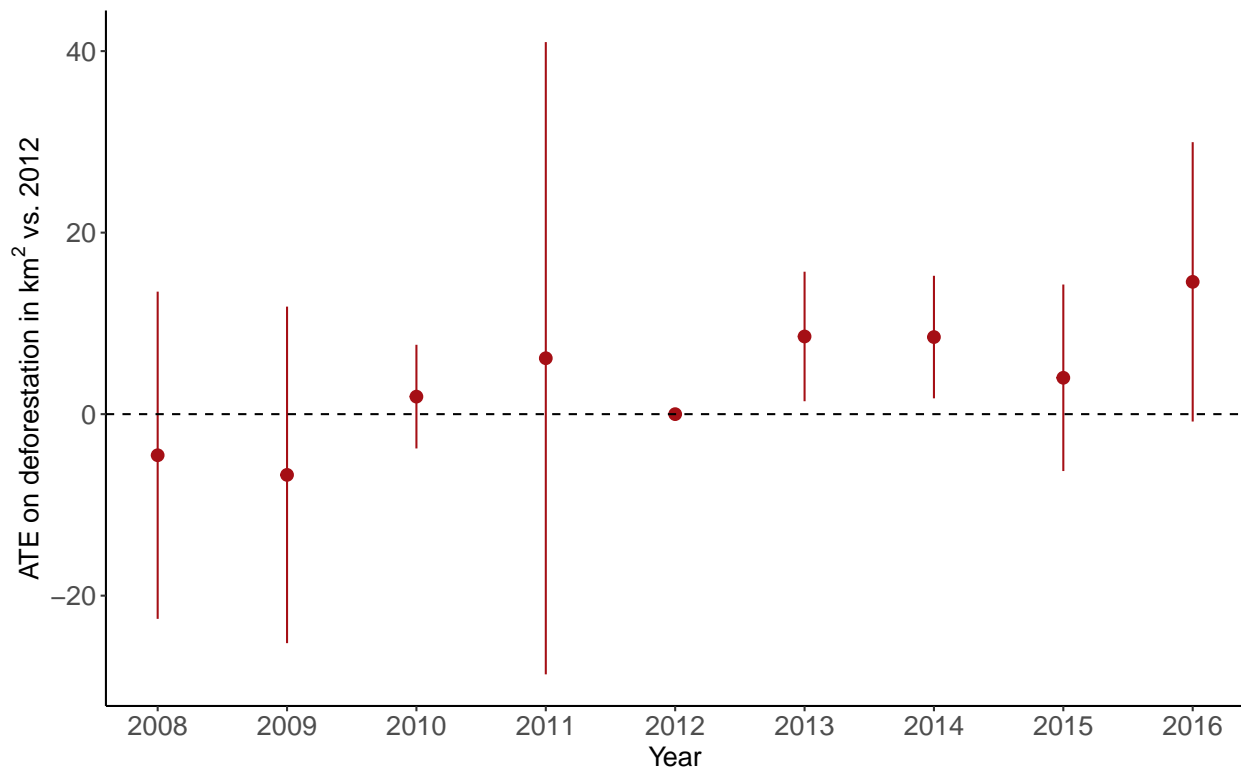


Before the regulatory change in 2013, we do not see significant differences between protected areas that are more and less exposed to illegal gold-mining. However, in 2013 and after, we observe overall positive and significant yearly effects on the size of deforestation.

**A.4. Event study of effect on environmental crimes - measured by mining-related IBAMA fines.** Figure 10 shows the additional effect on the number of mining-related IBAMA fines for protected areas with at least one gold deposit in them. Figure 11 shows the same additional effect, but now on the probability of observing IBAMA fines in more exposed protected areas.

Figure 10: Average difference in IBAMA fines between protected areas more and less exposed to illegal gold-mining, from 2006 to 2019 (95% c.i.)
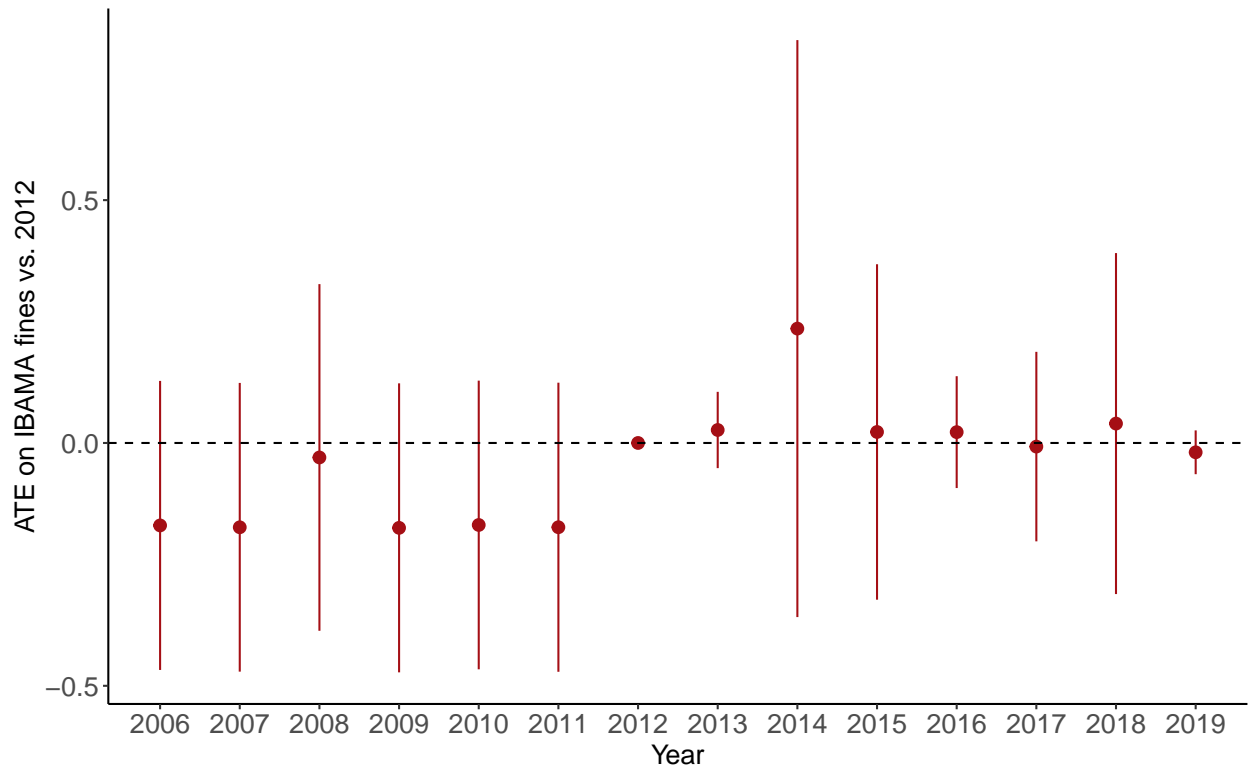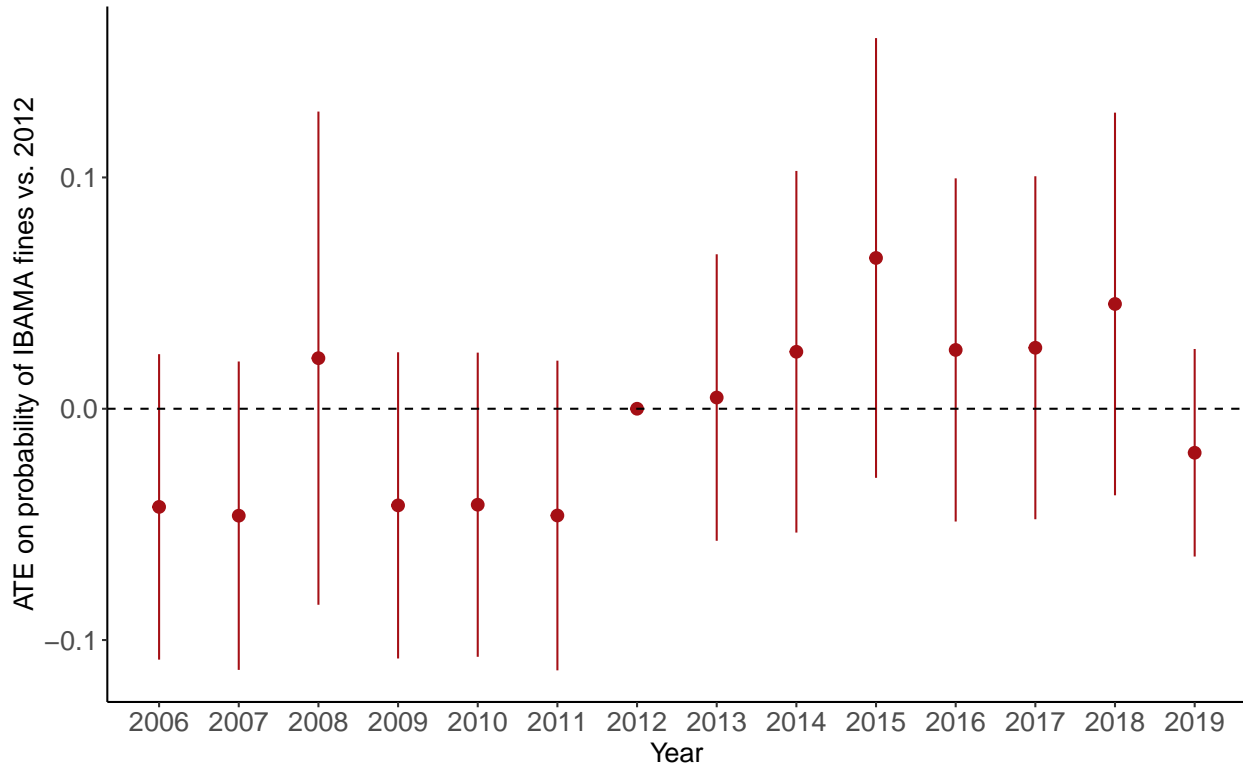
Figure 11: Average difference in the probability of observing IBAMA fines between protected areas more and less exposed to illegal gold-mining, from 2006 to 2019 (95% c.i.)



In both cases, we do not observe significant pre-trends before the regulatory change. Moreover, we do not observe significant effects in any particular year, and the small point-wise estimates are attributable to the sparsity of environmental crimes data. In any case, especially in Figure 11, the effect seems to be positive overall.

**A.5.   Alternative dependent variable: level of homicides.**  Another potential concern is that our results are driven by the denominator of our dependent variable, i.e., the population in each municipality. We have already shown in Table 9 that this does not seem to be the case. However, because Censuses only happen every 10 years, the population counts we use are **estimated** by IBGE and could be introducing some measurement error in our estimates. To check that, Table 12 shows how results behave when we remove this uncertainty from the equation and instead estimate the effect on the **level** of homicides weighing the regression by the inverse of the 2010 Census population.

Table 12: Average treatment effect of legislation change on total homicides in municipalities exposed to illegal gold-mining, from 2006 to 2019

| | Homicides | | | | | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Illegal Gold Dep. * I(Year≥ 2013) | 3.52* | 1.14** | 3.37* | 1.09** | 1.70 | 1.01** |
| | (2.00) | (0.51) | (2.02) | (0.50) | (2.14) | (0.49) |
| Gold Dep. * I(Year≥ 2013) | −1.87 | 0.02 | −2.03* | 0.01 | −1.89 | −0.11 |
| | (1.14) | (0.17) | (1.19) | (0.16) | (1.24) | (0.17) |
| Total mortality | 0.12*** | 0.09*** | 0.12*** | 0.09*** | | |
| | (0.01) | (0.01) | (0.01) | (0.01) | | |
| Kitchen gas sales (in tons) | | | 0.002 | 0.002*** | | |
| | | | (0.002) | (0.001) | | |
| Munic. covariates | X | X | X | X | | |
| Year FE * Munic Covariates in 2005 | | | | | X | X |
| Inverse Population Weights | | X | | X | | X |
| N municipalities | 769 | 769 | 769 | 769 | 769 | 769 |
| Observations | 9,228 | 9,228 | 9,228 | 9,228 | 10,766 | 10,766 |
| R$^2$ | 0.97 | 0.92 | 0.97 | 0.92 | 0.96 | 0.89 |

*Notes:* All specifications include municipality fixed effects and state-year fixed effects; (1) Includes contemporaneous level total deaths, suicides, deaths in traffic, as well as log of GDP per capita (only available until 2017), share of agricultural GDP; (2) Same as (1), but weighed by the inverse of population from 2010 Census(3) Same as (1), but also includes sales of kitchen gas (tons) to proxy for population growth; (4) Same as (3), but weighed by the inverse of population from 2010 Census(5) Includes interaction of year fixed effects with 2005 level of same covariates as in (3); (6) Same as (5), but weighed by the inverse of population from 2010 CensusAll errors are clustered at municipal level. *p<.1; **p<.05; ***p<.01

We see that results remain qualitatively similar to those in our previous analysis, either with (odd columns) or without (even columns) inverse population weights. Moreover, they are robust to using contemporaneous level of mortality as covariate (Columns 1 and 2); or kitchen gas sales as a proxy to population (Columns 3 and 4); or the fixed level of these covariates in 2005 interacted with year dummies (Columns 5 and 6). Overall, homicides increase after the regulatory change in 2013 in those municipalities exposed to illegal gold mining. Conversely, homicides decrease or remain stable in those municipalities exposed to legal gold mining, suggesting again that there might be a migration from legal to illegal gold activities.